The role of eye movements in the figure perception

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THE ROLE OF EYE MOVEMENTS IN FIGURE PERCEPTION

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ABSTRACT

The figure-ground distinction is particularly interesting where the same stimulus can give rise to more than the one interpretation of figure. The work presented here examines the role of eye movements in such figure perception.

The figure-ground dichotomy is first elaborated and stimuli which can give different figural interpretations are classified as reversible perspective or ambiguous figures. Theories which have been proposed to account for such figure perception are then reviewed and it is argued that a schematic map theory offers a plausible explanation.

The parameters which have been studied with regard to these stimuli are then considered and it is argued that the role of eye movements has not been adequately investigated. Stimuli are then proposed to be composed of elements which are differentially weighted towards each figural aspect. Figure perception is largely a result of an observer selectively attending to these elements as determined by the schematic map. Eye movements function to move such attention about the stimulus.

A series of afterimage experiments then examines the existence of such elements in a line drawing of Boring's ambiguous figure. The response of figure was found to be governed by the elements to which the subject could attend. Two free-viewing experiments are then reported which demonstrated that in a non-stabilised condition the immediate response of figure was determined by the elements present in the stimulus. No age-related effects of such elements were found when children served as subjects.

Eye movement types and recording techniques are then reviewed and an inconspicuous recording method developed. Subjects' eye movements were then recorded as they viewed versions of the ambiguous figure. The results are interpreted as supporting a schematic map explanation. A model is finally developed to account for the role of eye movements in figure perception.

PREFACE

The process of figure perception whereby part of a stimulus display is perceived as figure, and the rest of the display becomes ground, has been the subject of much inquiry. The most interesting example of this figure-ground distinction is where different figural interpretations are possible with the same display, as this situation then permits investigation of how the figural process has occurred. The work presented here considers the role of eye movements in this perception of figure. The overall layout of the thesis is now outlined.

In Chapter 1 the figure-ground distinction is elaborated and the various types of stimuli which can give rise to more than the one interpretation of figure are discussed and classified as either ambiguous or reversible perspective figures. The theories which have been proposed to account for figure perception, as well as the fluctuation between the alternative figural aspects in these stimuli, are then considered. Finally it is suggested that Hochberg's (1968) theory of schematic maps, which involves both eye movements and selective visual attention, offers a plausible account of figure perception.

The main parameters which have been investigated with both ambiguous and reversible perspective figures are reviewed in Chapter 2. These are considered as: stimulus factors, viewing conditions, instruction and response techniques, and observer variables. Approaches which have attempted to either rule out the involvement of eye movements in figure perception, or alternatively specifically studied eye movements, are discussed in detail. The need to both adequately and inconspicuously record eye movements in such work is elaborated.

Consideration of the effects of prior experience and of the manner in which different versions of ambiguous figures have been constructed leads to the proposal that pictures can be considered to be composed of elements. Each of these elements represents some part of one or more real-world objects. It is argued that with ambiguous and reversible perspective figures each of these elements are differentially weighted in their representation of parts of the possible figural aspects. It is hypothesised that the observer selectively attends to these elements and that this process governs the response of figure. Eye movements serve to shift selective visual attention about the stimulus display as a result of the expectations of the schematic map.

Various experimental hypotheses are generated and a guide is presented to the subsequent Chapters in which these are investigated. A suitable stimulus which can give rise to more than the one interpretation of figure is first chosen and its elements empirically determined. A stabilised image technique is then used to investigate the effect of selectively attending to the different elements. This work is then extended to a free viewing situation. Finally, observers' eye movements are recorded as they freely view the stimulus. Thus the experimental work divides into three stages; the afterimage experiments, the free viewing experiments and the eye movement experiment.

In Chapter 3 Boring's ambiguous figure is selected as a suitable stimulus for this research and a line drawing of it is derived. It is proposed that this drawing can be considered as composed of 4 important elements. The effect of being able to selectively attend to these is investigated using a stabilised image technique. The various methods of attaining such a stabilised image are briefly reviewed and an afterimage technique is selected as the most appropriate. Three afterimage experiments are then described which use variations of the line drawing to investigate the role that both fixation position and the presence of the stimulus elements have upon the perception of figure. It is argued that the results demonstrate that the response of figure is largely governed by the relative weightings of the various elements to which the observer can attend at each fixation position. Both peripheral as well as foveal vision are proposed to be important factors.

In these afterimage experiments the fixation position of the subject is determined by the experimenter. The question of whether the response of figure is similarly dependent upon the presence of the weighted stimulus elements when the subject is free to look at the stimulus is examined in Chapter 4. Two experiments are presented here where the subjects were free to look at different versions of the line drawing and asked to immediately report its appearance. These experiments again demonstrated that the response of figure is largely governed by the presence or absence of the elements. Both children and students were used in these experiments to examine whether any age-related effects in the utility of the elements existed. No such effects were found although it is proposed that the precise manner in which the elements are actually integrated into the schematic maps may possibly be age-related.

Having established the effect of these elements upon figure perception in both stabilised and free viewing conditions the final experiment examined the eye movements of subjects as they looked at the ambiguous figure to see whether they did actually attend to the stimulus elements. First, however, a suitable eye movement recording technique had to be determined which would not sensitise the subjects to the fact that their ocular behaviour was being recorded.

The development of such a technique and the construction of suitable apparatus which would inconspicuously record the subjects' eye movements formed a large part of this research. This is detailed in Chapter 5 after reviews of both the various types of eye movements and also other eye movement recording methods. Two alternative techniques of data analysis which were developed are then described. The errors inherent in this approach are considered and a method of accounting for these is detailed. The results of an evaluation trial of the recording technique are also presented.

Chapter 6 then reports an experiment where subjects' eye movements were recorded as they freely viewed versions of the line drawing and alternated between the two figural aspects. This experiment demonstrated that subjects concentrated upon the stimulus elements, their response of figure being governed by the elements fixated. The results are interpreted as supporting the proposed schematic map explanation.

Finally Chapter 7 presents the conclusions of the various experiments and a model is presented which is proposed to account for the role of eye movements in figure perception. Some proposals for future research are then briefly outlined.

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My wife, Margot, has both supported and encouraged me throughout and to whom this tome is dedicated. Lastly, my daughter Corinne and Zig have both played their respective inspirational roles.

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DECLARATION

The Pilot Study and Experiment 1 were initially carried out as part of the author's final year dissertation in part fulfillment of the requirements for the B.Sc. degree in Psychology, University of Durham (1972). The results of this experiment have been extensively re-analysed. This work is included here as it forms the starting point of the reported research.

Appendix G is a published paper which was written by the author in conjunction with G. Walker-Smith and J.M. Findlay. The work it reports formed a final year dissertation by G. Walker-Smith for the B.Sc. degree in Psychology, University of Durham (1975). This work was carried out using the equipment detailed in Chapter 5. The author played a major role in this work which was conducted at the same time as the research reported in this thesis.

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C H A P T E R 1

FIGURE PERCEPTION

1.1. INTRODUCTION

The perception of figure in a stimulus display is not a fully understood process despite the early distinction made between figure and ground (Rubin, 1915). The intriguing fact that some stimuli can give rise to more than the one interpretation as figure has led both to the formulation of various theoretical explanations as well as to experimental studies of the parameters affecting this process. The research presented in this thesis is concerned with the possible role of eye movements as a parameter in such figure perception.

In this chapter the distinction of figure and ground is first elaborated and then the fluctuation of this relationship is considered. The various stimuli which can give rise to different interpretations as figure are then detailed under the headings of Reversible Perspective and Ambiguous Figures. Other perceptual events possibly related to the fluctuation of such stimuli are next briefly considered.

The different theories proposed to account for the perception of these stimuli are detailed and the evidence for each is assessed. Each of these theories to some extent implicates or denies any possible role of eye movements. It is finally proposed that Hochberg's theory provides a possible worthwhile explanation for the perception of figure but one which requires experimental investigation.

1.2. THE FIGURE AND GROUND DISTINCTION

The dichotomous concept of figure and ground has become somewhat ubiquitous in the psychology of form perception. The first definition of it was proposed by Rubin (1915) that:

> "when two fields have a common border, and one is seen as figure and the other as ground, the immediate perceptual experience is characterised by a shaping effect which emerges from the common border of the fields and which operates on one field, or operates more strongly on one than on the other. The field which is most affected by this shaping process is figure, the other field is ground." (p. 195, Beardslee and Wertheimer, 1958).

The common border can be either a contour separating two juxtaposed fields of different brightness or colour. Alternatively, it can be a line which as Kennedy (1974) points out is a narrow strip of pigment enclosed by two contours. Rubin further elaborated the difference between figure and ground in that the contour has a different significance for the two fields. The figure is thus perceived as having shape and 'thing-character' being bound by the contour or line. The ground possesses 'substance-character', both appearing to extend behind the figure and to be spatially localised further away than the figure. Qualities specific to the figure are that it is more impressive, dominant and remembered better.

Rubin in fact pointed out that two limiting cases are possible; either both fields could be perceived simultaneously as figure (the shaping process of the contour affecting both fields equally) or neither field becoming figure (both being unaffected by this process). Subsequently, Rubin has often been considered to have proposed that the shaping process affects only one of the adjoining regions. For example Attneave (1971) stated that "it is quite impossible to see both sides of the contour as figure at the same time." Koffka (1935) partially considered this concept when discussing the problem of unum and duo - when an outline figure contains a central dividing contour whether only the whole outline is perceived as figure (unum) or whether each half is considered figural (duo). Kennedy (1973) points out that Rubin was only describing a figure-ground organisation which can occur, not one which will occur.

Rubin's original phenomenological observations have had wide acceptance such that the figure-ground distinction has now become a basic tenet of form perception. The great impetus for this came with Gestalt Psychology which popularised this concept to such an extent that Hochberg (1974) has recently considered it to be one of the 'analytic tools' to be offered by this school of thought. Wertheimer (1923) in setting forth the Gestalt principles of organisation took figure-ground segregation as a sine qua non;"..in the visual field, when figures composed of discontinuous parts (e.g. dots) become segregated on an otherwise quite homogeneous ground." In applying the Gestalt principles Koffka (1935) stated that when "a line forms a closed, or almost closed figure, we see no longer merely a line on a homogeneous background, but a surface figure bounded by the line." Likewise, Köhler (1920) earlier affirmed that "terms such as figure and ground may be used in visual space with perfect assurance that they designate concrete and phenomenally real modes of being." The segregation of figure was, the Gestaltists argued, due to factors such as closure, good shape or good continuation.

Succeeding authors have asserted the essentiality of figure and ground. Boring (1942) in referring to Rubin's work points out that "a visual perception normally divides into two fields: a figure, which is usually the object of attention, and a ground, which occupies the rest of the perception." Similarly Vernon (1965) considering the figure-ground experience wrote "it is one which is fundamental in perception from very early childhood." Dember (1965) proposed that:

> "Every meaningful perceptual experience seems to require in its description the property of 'figuredness.' That is, phenomenally, perception is more than a mere collection of unrelated, unintegrated, sensory elements. The units of perception are, rather, figures, or things, segregated from their backgrounds." (p.146).

This segregation of figure and ground is essentially what Hebb (1949) meant by 'primitive unity.' For Neisser (1967) discussing the iconic memory, the pattern was already resolved into one or more segregated figures by a global 'preattentive' process. In describing the functioning of this sensory (iconic) buffer Restle (1975) has proposed four levels of immediate visual analysis where the figure is first segregated from the background before the figure and contour are further analysed.

Stemming from this background of work Kennedy (1974) sums up the modern version of Rubin's figure-ground principle to be that such an organisation is an inevitable consequence if a line or contour is present. By thoroughly reviewing all of the available original work of Rubin, however, he concludes that this is a modern misinterpretation and that nowhere does Rubin actually state that contours necessarily give rise to figure and ground. He further elaborates upon Gibson's (1951) earlier formulation and suggests that the figure-ground dichotomy is a pictorial phenomenon which is relevant to the perception of lines and contours but not necessarily basic to perception itself as is so often thought. Certainly the concept does require a 'common border' as no perception of figure-ground is obtained with completely homogeneous fields (Engel, 1930; Metzger, 1930). Even when a figure is present, factors such as poor illumination can lead to the loss of figure-ground differentiation (Pikler, 1928; Liebmann, 1927).

Notwithstanding such criticisms and limitations then, it may be taken that figure-ground organisation is a commonly experienced phenomenon of form perception which by nature of its apparent immediacy has been taken to be a basic perceptual process.

1.3. REVERSIBLE FIGURE AND GROUND

To illustrate the figure-ground distinction Rubin made use of a Maltese cross figure with eight equal sectors. In addition to the 'immediate perceptual experience' of seeing four of the alternate sections as a figural cross upon a background, Rubin noted that reversal could occur such that the previously perceived background now became figure. When this occurred the new figure had all the relative figural qualities of the previous figure now relegated to background status. In considering the parameters affecting which alternative would be perceived as figure in such situations, he proposed that "if one of the two homogeneous differently coloured fields is larger than and encloses the other there is a great likelihood that the small, surrounded field will be seen as figure." Rubin noted that the change from one perception to the other was in some cases rather gradual whereas in others it occurred immediately. Rubin also used the example of his 'vase-faces' figure to illustrate how differently the stimulus could be perceived when reversal of figure and ground occurred.

1.4. PERCEPTUAL AMBIGUITY

This phenomenon of figure reversal illustrates the ambiguity of perception when considering pictorial matter. This is because a two dimensional stimulus can represent a multitude of stimuli in the real three dimensional world (Gregory,1970). The spontaneous reversal of perception in such pictorial figures has been referred to as flip, reversal, ambiguity, fluctuation or alternation. This has led to the confusing use of the term 'ambiguous figure' to refer to all such figures (Porter,1938), but this is unfortunate as a worthwhile distinction into two major classes of stimuli can be made (Fisher,1968b; Gregory, 1970).

1.5. THE TWO MAJOR CLASSES OF PERCEPTUAL AMBIGUITY

Some figures when they appear to alter do so by apparently changing in depth, these can be considered 'reversible perspective' figures, the other major class involves a reversal of interpretation or meaning and are the 'ambiguous' figures. By this definition the reversible figure-ground stimuli considered in the previous section are a sub-type of ambiguous stimuli.

The term reversal is used hereafter to refer to the change occurring in the former figures, and fluctuation, alternation, or ambiguity are used for the latter. Also the terms percept, alternative, and aspect are used interchangeably here to refer to one of the possible interpretations of the stimulus.

These two classes of figures may well represent the ends of some continuum (Price, 1971) with a common underlying causal factor. Alternatively, they may be quite separate entities requiring quite separate explanations. For instance, Axelrod and Thompson (1962) have even questioned the assumption of a unitary process underlying such figures as the static Necker cube and the dynamic 'rotating pin pattern' both of which exhibit reversal of perspective.

The work presented in this thesis is more pertinent to the ambiguous figures, but the other classes of stimuli are included to demonstrate both the relationship of the ambiguous figures to these other stimuli as well as illustrating the various theoretical developments.

1.5.1 Reversible Perspective

A remark by Wheatstone to the effect that the outline drawings of geometrical solids in the eleventh book of Euclid were often seen to reverse themselves caused Boring (1942) to comment that the phenomenon of reversible perspective had possibly been known to geometers ever since Euclid's time.

Three types of reversible perspective figures can be distinguished: static, rotating and those involving incompatible local depth cues.

Static Figures. Necker (1832) in describing his observations in Switzerland drew attention to the sudden and involuntary change in apparent position of a crystal. Necker's original drawing has subsequently been drawn as a cube and referred to as Necker's cube which has remained the most popular reversible perspective stimulus for research. Other examples are the Schröder staircase and also Mach's truncated pyramid and book figures. These are shown in Figure 1.1.

Typically such figures are considered to reverse between two particular aspects. Other interpretations of the stimulus are, however, possible. Taylor and Henning (1963) mention a subject's report of twenty two different forms of the Necker cube within ten minutes. Ammons, Ulrich and Ammons (1959) also point out the many variations of aspect of this same figure as does Martin (1967), with a similar figure.

Rotating Figures. When either two or three dimensional stimuli rotate they spontaneously appear to change their direction of movement. Howard (1961) and several subsequent workers have used one and two rotating skeletal cubes. Lissajous figures (Fisichelli, 1946) and shadows of rotating pin patterns (Brown, 1955) are other examples. Day and Power (1965) have used rotating flat patterns.

Figures Involving Incompatible Local Depth Cues. Two classes of stimuli contain local depth cues which are incompatible with one another. These are the Impossible Figures and the Impossible Objects. Unlike figures such as the Necker cube no 'solution' or aspect fits the entire figure. Thus they do not reverse in depth between two possible aspects, instead they appear to constantly change. Any perceptual solution only appearing to be locally effective.

Impossible Figures. Also called paradoxical (Gregory,1970) or incompatible figures (Fisher,1968b). These are a class of pictorially represented objects which generally could not validly exist in nature. The drawings of Escher (e.g. Locher, 1971) illustrate the principles of such stimuli. Penrose and Penrose (1958) presented the first of such figures including an impossible triangle and an impossible 'three-triangle' figure. Schuster (1964) drew attention to the 'three stick clevis' alternatively named the Devil's tuning fork' which had first appeared in an aviation magazine.

Baldwin (1967) has pointed out that figures such as the 'Devil's tuning fork' rely on the representation of a cyclindrical object by a pair of lines and the representation of a rectangular bar which uses three lines. Hayward (1968) has used this to construct several figures as did Robinson and Wilson (1973) who have presented variations of the 'impossible colonnade' figure.

Impossible Objects. Real objects can be constructed which represent the above class of impossible figures. However, these objects only become impossible when seen or photographed from a particular angle, viewed from elsewhere they appear as an odd shaped construction. Penrose and Penrose (1958) present a photograph of an apparently continuous flight of steps and Gregory (1970) illustrates an apparently 'real' impossible triangle. Masterman and Kennedy (1975) have more recently demonstrated a construction of the 'Devil's tuning fork.'

1.5.2. Ambiguous Figures

As a generic class ambiguous figures include; the already discussed reversible figure-ground figures, reversible silhouettes and the 'true' ambiguous figures.

Reversible Silhouettes. A variety of objects when drawn or otherwise perceived in silhouette form appear to reverse. Porterfield (1759) gives possibly the first account of such reversibility. Sinsteden (1860) saw the silhouette of a windmill against the evening sky and noted that its sails appeared to reverse their direction of movement as they rotated. Such stimuli may appear to reverse in depth as in Porterfield's windmill figure or may merely represent two different interpretations of the same silhouette (e.g. Tinbergen's (1951) 'goose and hawk', shown in Figure 1.1). Thus, these stimuli can be regarded as belonging to either class of ambiguous or reversible figures.

Ambiguous Figures. An ambiguous figure is one in which there is more than one perceptual interpretation, usually of the same figural area. Thus, a 'reversal' occurs which does not involve a reversal of apparent depth - rather it is a reversal of 'interpretation.'

The best known example of an ambiguous figure is that of Hill (1915) as drawn for Puck magazine and later presented to psychologists by Boring (1930) as 'my wife and my mother-in-law' (Figure 3.1). This figure is the mainstay of the work presented in this thesis and hereafter is referred to as Boring's ambiguous figure. It involves a picture of a woman's face which can either be seen as a young or an old woman. Other examples of such two-aspect ambiguous figures are Jastrow's (1900) duck and rabbit, Kolers' (1964b)'the boys from Syracuse' and Botwinick's (1961) 'husband and father-in-law.' Leeper's (1935) 'pirate and rabbit' is interesting as both of the possible aspects are hidden within an overall scene. Other examples of such hidden figures are Fernberger's (1950) 'Napoleon and tomb at St. Helena' or Carmichael's (1951) similar 'The tomb and shade of Washington.' Some figures are more difficult to interpret, (e.g.

Dallenbach's (1951) 'concealed cow' picture) and some may be helped by inverting the stimulus (Weigl, 1927). Some of these are illustrated in Figure 1.1.

Figures representing more than two alternatives can also be constructed. Fisher (1968c) has devised a three aspect version of Botwinick's figure as well as other three, five and seven possible aspect figures, (1967a).

1.6. RELATED PERCEPTUAL EVENTS

The phenomenon of ambiguity or reversibility has been linked to other perceptual effects which show somewhat similar periodicity, with the suggestion that some common process underlies all these. Walker (1975) and earlier McDougall (1906), compared binocular rivalry and ambiguous figure alternation and proposed that just such a common mechanism underlies both phenomena although Washburn and Gillette's (1932) results found little correlation between them. Lechelt (1976) has also recently demonstrated some dissimilarities between binocular rivalry and a Rubin's cross figure. Levelt (1967) has related the distribution of the dominance times in rivalry to 'flicks' of eye movement. As discussed later a similar explanation for ambiguous figure alternation has been proposed. Köhler and Wallach (1944) have related figural after-effects to figure reversals, although Cohen (1959) has pointed out

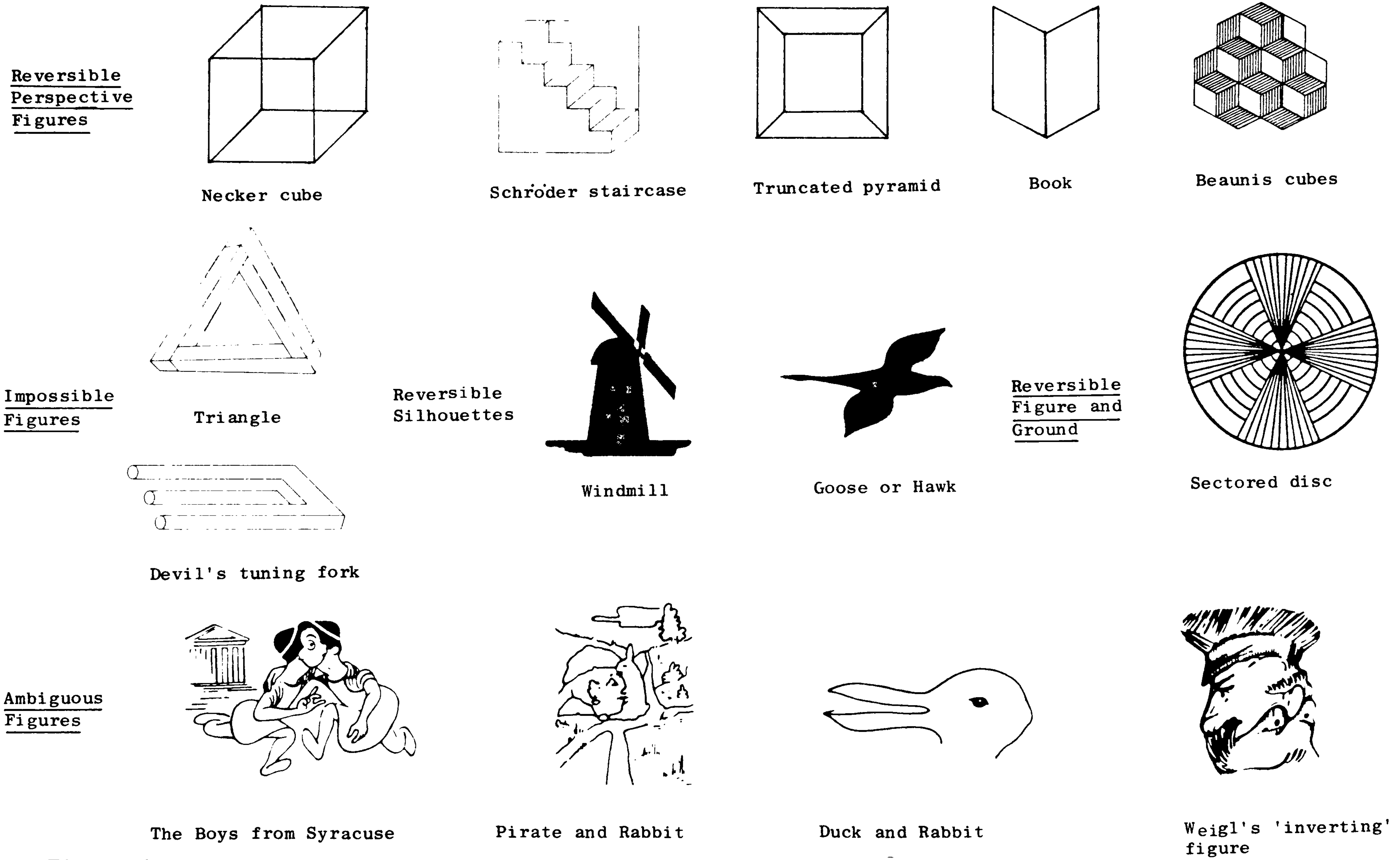


Figure 1.1 Some examples of ambiguous and reversible perspective figures

differences between these.

1.7. THEORETICAL APPROACHES: A BRIEF GUIDE

The question of how the one stimulus, whether a reversible perspective or an ambiguous figure, can give rise to more than the one percept has had several possible theoretical explanations. Some of these purport to consider both of these major classes of stimuli as well as other possibly related events such as figural after-effects. Other theories are quite specific and are concerned only with a particular class or sub-class of figure (e.g. Cowan, 1974). For a theoretical approach to be fully acceptable it must not only explain how more than the one percept can occur, but also why one particular percept initially occurs rather than another, why and how alternation takes place, and it should also describe the time course of such alternation. Not all theories do this. Some concentrate on one aspect, e.g. the stochastic process theories emphasise the alternation sequence. Some theories have used these figures as a mainstay of their approach (e.g. Hochberg, 1968), whereas others come from different areas of psychology and have then been applied to these particular stimuli (e.g. Learning Theory).

In the following sections the different theoretical approaches are considered. The following is offered as a brief guide to their layout and inter-relatedness.

The early theories of these stimuli considered that alternation was due to either peripheral (e.g. eye movements) or central processes. Two of the latter approaches, namely those of McDougall and Satiation Theory, have given rise to much experimental investigation and are described in some detail. Possibly sharing similarities with Satiation Theory is the application of Learning Theory which is next considered. In contrast to Satiation Theory stand the Stochastic Process Theories which emphasise the stochastic nature of the alternations whereas the former considers alternation to be more systematic. Also contrasting with Satiation Theory, this time in terms of physiological processes, is the theory of Hebb. Of less import here are the two theories of Yacorzynski (1966) and Cowan (1974) which are then briefly described. Next the three modern theories of Information Pick-Up, Perceptual Hypotheses and Information Processing are considered. Finally the theory of Hochberg is elaborated. It is suggested that this final theory offers a possible worthwhile explanation of the behaviour of these ambiguous and reversible perspective figures in that it encompasses diverse processes such as eye movements and also possibly satiation. However, it does require experimental investigation. This theory forms the starting point for the theoretical and experimental approach of the work presented in this thesis.

Throughout the elaboration of the various theories the role of eye movements in the perception of these stimuli is considered, whether almost exclusively (as in the early peripheralist approaches), dismissed (e.g. Satiation Theory), or as one of a number of possible contributing factors.

Critical experimental evidence for each theory is presented where it exists.

1.8. EARLY THEORIES

Early explanations of the phenomena of ambiguity and reversible perspective can be considered to represent two camps; the peripheralists and the centralists. Necker, Brewster, Sinsteden and Wundt all emphasised peripheral processes such as fixation, accommodation, or eye movements. Others, including Wheatstone, Oppel, Schröder , Hering and Helmholtz all considered more central mechanisms.

1.8.1. Peripheral Process Theories

Wundt (1912) proposed that space perception was composed of the association of the 'series of local sensation-colourings' with the sensation of movement. Reversibility of perspective is thus initiated by sensory processes and the associated eye movements.

Brewster (1826) in considering the Intaglio moulds used to make bas-reliefs, pointed out that by directing the eyes steadily we can coax ourselves into believing that the Intaglio is itself a bas-relief (a more recent demonstration of essentially the same phenomenon is given by Gregory, 1970). In a later paper Brewster (1847) proposed that it was possible"by the eye alone, to raise a complete hollow mask of the human face into a projecting head."

In drawing attention to the apparent reversal of depth in a crystal, Necker (1832) wrote:

> "The only thing I could observe was, that at the time the change took place, a particular sensation was felt in the eye (for it takes place as well when only seen with one eye, as well as both eyes), which proved to me that it was optical, and not as I had at first thought a mental, operation which was performed." (p.336).

In similar fashion Titchener (1899) discussed the 'measuring eye', emphasising each 'look' of the object and its 'welding' with eye muscle sensations stating that "in all cases of space illusion the final appeal is to the eye." The role played by the muscles of accommodation and fixation was also emphasised by Muensterberg (1925).

1.8.2. Central Process Theories

Hering, representing a centralist position considered every visual sensation to be correlated to a physical process in the nervous apparatus and stated (quoted in James, 1891):

> "Things actually diverse may give similar or almost identical retinal images, e.g. , an object extended in three directions, and its flat perspective picture. In such cases it often depends on small accidents, and especially on our will, whether the one or the other group of sensations shall be excited." (p. 262).

He goes on to propose:

> "Whenever the retinal image is of such a nature that two diverse modes of reaction on the part of the nervous apparatus are, so to speak, equally, or nearly equally imminent, it must depend upon small accidents whether the one or the other reaction is realised. In these cases our previous knowledge often has a decisive effect and helps the correct perception to victory." (p. 262).

James, himself, argued that the present sensations were interpreted by 'the understanding' which "recalls previous space sensations with which the present one has been associated." His emphasis upon such a central factor is illustrated by:

> ".....we see now this object and now that, as if the retinal image per se had no essential space-import. Surely if form and length were originally retinal sensations, retinal rectangles ought not to become acute or obtuse, and lines ought not to alter their relative lengths as they do. If relief were an optical feeling, it ought not to flap to and fro, with every optical condition unchanged."(p. 257).

In considering the 'illusions' of reversible perspective, James stated:

> "we may sum up our study of illusions by saying that they in no wise undermine our view that every spatial determination of things is as originally given in the shape of a sensation of the eyes. They only show how very potent certain imagined sensations of the eyes may become." (p. 266).

James accepted the role played by eye movements but did not attach too much importance to them:

> "These sensations, so far as they bring definite forms to the mind, appear to be retinal exclusively. The movements of

> the eyballs play a great part in educating our perception, it is true, but they have nothing to do with constituting any one feeling of form. Their function is limited to exciting the feeling of form....." (p. 266).

Helmholtz (1910), considering Sinsteden's windmill figure, wrote, "...owing to external accidents or movements of the eye, first one opinion prevails, and then the other. But an intentional change of opinion may also be produced by imagining the appearance of the alternative figure....." "......now conscious attention has been called to the fact that it is a question of apperception." Apperception he defined as a perception accompanied by the sense-impressions in question. The apperception of depth he argued involves factors which demonstrate "the influence experience has on the seemingly direct perceptions of the senses, with which the mental activities have had nothing to do." Thus the present object one is viewing 'awakes' the previous memory experiences of similar objects which act to determine the present immediate perception.

1 .8.3. Summary

To sum up these early theoretical approaches then, Slaughter (1900) concluded that fluctuations of attention did not depend on either apperception or on changes in the sense organs, whereas Guilford (1927) in considering the fluctuations of liminal stimuli, argued that a number of factors both peripheral and central were involved.

Most of the subsequent theories have tended to emphasise that alternation occurs at some level in the nervous system higher than the eye. Thus, in a sense these are centralist theories, however, they usually also encompass peripheral factors such as eye movements thus agreeing with Guilford. The distinction of these later theories into 'peripheral' or 'central' is not then fully applicable. However, the next two theories considered do represent a position which discounts peripheral factors.

1.9. MCDOUGALL'S LOCAL FATIGUE THEORY

In a series of articles on the physiological factors of the attention process McDougall (1902, 1903, 1906) expounded his essentially centralist view. His interest was in the "rate of alternation of the states of consciousness during the struggle of two different visual fields and the changes of mode of apperception of ambiguous figures." The visual stimulus largely used for his work was a triangular shaped figure composed of black discs arranged in rows and columns, on a white background. He found that movement of the eyes along any of the linear groupings (horizontal, vertical or angular) of the dots facilitated the appearance of that grouping. Reversals of the groupings could be achieved by moving the eyes in a particular fashion. This, he states, is in accord with the findings of Titchener (1901) using the Schröder staircase and Loeb, (1887) with the Necker cube. McDougall, however, stressed the importance of attention and not the eye movements themselves, although he considered them to stand in a 'reciprocal' relationship:

> "each mode of Attention to(the figure)... tends to determine a certain mode of activity of the eye muscles and this mode of activity of the eye muscles, when otherwise determined (accidentally or voluntarily) tends to bring about that particular mode of Attention." (p. 487, 1903)

In his 1906 paper McDougall considered the effect of voluntary effort in controlling the perceived aspect. He proposed that this effect was indirect in that:

> "it directly effects only the adjustment of the sense-organ and it is this adjustment of the sense-organ alone which favours the predominance of one or other mode of perception." (p. 330).

He pointed out that, with practice, it was possible to perceive the alternate forms of the Schröder and Necker figures by executing just those eye movements that were advocated by Titchener and Loeb as necessary for the alternate aspect and he considered that either form could in fact be "called at will."

For McDougall the essential determinant of attention, apart from the intensity, novelty or other compelling features of the sensory stimulus, was the cerebro-ideational activity, i.e. the "play of excitement among the organised system of neural elements of which the higher levels of the brain are composed."

McDougall proposed that attention to any object had a neural correlate in a flow of nervous energy from the efferent side of the central nervous system. This flow is through some paths which include those of the higher brain levels. The particular route the flow takes is dependent upon the resistance of the path. This resistance is produced by the process of nervous transmission which included fatigue. The onset of such fatigue is directly related to the degree of 'canalisation' of the path. In higher level paths with low canalisation a very brief period of nervous excitement induces fatigue such that an alternate path becomes favoured. According to McDougall then, this is how alternation of ambiguous and reversible perspective figures occurs. A regular alternation occurs between the activity of two rival systems, in the upper brain levels which reciprocally inhibit one another.

1.9.1. Experimental Evidence

In an experimental test of McDougall's local fatigue theory, Flügel (1913b) found such fatigue was not manifested for all his subjects and concluded that fatigue plays only a minor role. In his 'Outline of Abnormal Psychology', McDougall (1926) also proposed that the fluctuation of such figures would be related to the personality dimension of introversion - extroversion, such that introverts would produce more alternations. An experimental attempt to confirm this by Guilford and Frederinsen (1934) failed to find virtually any correlation between fluctuation rate and the degree of introversion - extroversion.

Guilford and Braly (1931) found no relationship between fluctuation rates and either the Marston scale or Neymann-Kahbted test. McDougall (1929) further predicted that extroverts would be more affected by alcohol and similar drugs. Guilford and Braly (1931) found no such relationship. Guilford and Hunt (1932) using a different personality test (the Laird test) again found no relationship between fluctuation rate and extroversion. George (1936) considered the possibility that the personality tests confused traits and developed a scale for extroversion-introversion finding correlations between scores on this scale and fluctuation rates which were in accord with McDougall. Franks and Lindahl (1963) also report data supporting McDougall but point out that the opposite position of Eysenck (who proposed that extroverts would show more reversals) could also be supported in a modified form by their data. Porter (1938) also supported the idea that introverts produced faster fluctuation rates. Considering manic depressive patients as displaying extroversion to a pathological degree, Philip (1953) compared the reversal rates of a large number of psychotics on a Lissajous figure. There was a slight tendency for manic depressives to reverse less than schizophrenics (similarly, Hunt and Guilford, 1933).

1.9.2. Summary

In conclusion then McDougall's theory has had equivocal support with most investigators examining the proposed personality related fluctuation rate. Apart from this aspect the theory is probably only of historical interest.

1.10. SATIATION THEORY

1.10.1. Köhler and Wallach

An approach formally equivalent to that of McDougall's and pre-empting it (Howard, 1961) was proposed by Köhler and Wallach (1944) who examined the behaviour of reversible figures as part of their study of figural after-effects. Their finding that the speed of reversal increased with viewing time led them to propose the principle that "the prolonged presence of a figure in a given location tends to operate against further presence of this figure in the same place." They considered that:

> "the presence of a figure in the visual field is associated with a specific figure process in the visual sector of the brain, and that this process gradually alters the medium in which it occurs. In a reversible figure a redistribution of the figure process seems to occur when that change has reached a certain level." (p. 270).

The alteration of the medium was referred to as satiation and this originally had no particular implications beyond the fact that the prolonged presence of a figure caused a 'depressed' condition of the medium. Satiation was seen as being caused by any specific entity in the visual field, it being stronger in the more closed area. Visual field entities were considered as being associated with an electric current in the visual sector of the brain.

Köhler and Wallach saw the nerve tissue as a volume conductor in which only electrolytic conduction was possible. They proposed that the current flowed in short loops near the boundary of the object, these loops becoming longer for further inside or outside an object. Thus, the greatest effect was at the boundaries and hence the strong effect of closed areas. This 'figure-current' had the effect of polarising the tissue through which it flowed thereby establishing electrotonus which survived the polarising current for some time and affected all subsequent currents in that region.

The term electrotonus was used to refer to two things. Firstly, the initial immediate electrolytic polarisation of all cell surfaces and secondly, the more gradual change of polarisability. Satiation was first considered to be equivalent to electrotonus, but more usually to the gradual change of polarisability. In a later paper Köhler (1965) distinguished between physical and biological electronus using the term satiation as equivalent to physical electronus, and electrotonus solely for the latter. The satiating effects develop and disappear very quickly whereas the electronic condition persists for some time, enhancing and accelerating the satiating effects of further currents. This has the effect that some tissues are in a high electrotonic state and, therefore, satiate very rapidly. This gives rise to the concept of statistical or permanent satiation (really an electrotonic condition according Köhler's (1965) definitions).

To explain the alternation of figures Köhler and Wallach (1944) proposed that the figures self-satiate, i.e., the figure changes due to its own satiating action, this being a temporary form of satiation. With the perception of the first aspect of the figure, satiation develops which acts against the continued further presence of this aspect until some 'certain level' is reached when the electric currents associated with the figure become redirected so that the second aspect is now perceived. This second aspect now satiates and the entire process is then cyclic.

Köhler and Wallach typically prescribed steady fixation of the stimulus in their experiments and indeed pointed out that this was the only condition which must be fulfilled for the establishment of temporary satiation. Regular scanning patterns of eye movements were incorporated into Köhler's later work such that these developed a "band of electrotonically charged tissue." This then extended the application of the theory to a wider range of viewing conditions.

1.10.2. <u>Physiological Evidence</u>

The physiological likelihood of such a system has been criticised. Lashley, Chow and Semmes (1951) attempted to disrupt the electrical currents by laying strips of gold foil on the visual cortex of a monkey. Such a good electrical conductor, they argued, should deflect the normal flow of cortical current so affecting the appearance of the stimulus. The fact that the animal could still discriminate between patterns learned prior to this surgical operation they took as evidence that such a current had little or no relationship to perception. Köhler (1965) has countered this criticism by pointing out that the metallic electrode would be so intensely polarised that little current would actually flow through it, so dismissing the experiment.

Similar pre- and post-operative performance was found in cats by Sperry, Miner and Myers (1965) after several cuts had been made in the visual cortex of these animals. Köhler (1965) argued that, on analysing the post mortem reports on these animals, they were in fact practically blind after the operation. To explain the animals post-operative performance he suggested that in the initial learning phase the animals were probably using other cues, as well as visual ones, and these other cues gave rise to the good later performance.

Other workers whilst supporting satiation theory have considered that attempts to relate 'figural currents' to know principles of neural function could only be made with difficulty. Price (1967b) asserts such a viewpoint. Dornic (1967) went further and argued that no special physiological significance should be attached to the concept of satiation.

The main physiological criteria of Köhler and

Wallach is that they assert that a stimulus is input to a particular location in the central nervous system (Robinson, 1972). Robinson instead proposes that different processes which occur at different times and places in the nervous system are all relevant to the resultant perception which militates against such an argument.

1.10.3. Experimental Evidence

Brown (1955) compared figural after-effects and a rotating reversible figure, concluding that the same physiological process underlies both (thus supporting Köhler and Wallach). However, Cohen (1959) has found that although there exist similarities between them an additional factor is relevant for reversible perspective reversals thus questioning the possible mediation of both by a common central process.

Using a test and inspection figure of Rubin's cross Hochberg (1950) investigated the non-directional nature of the satiation process; i.e. if both the test and inspection regions fixated by the subject were of the same or of opposite colour then Köhler and Wallach would argue that this should make no difference to the satiating effects of the test figure. Hochberg, however, found a decrease in dominant perception if the coincident parts of both figures were black on white or white on black (thus supporting the general phenomenon of satiation), but found no change in the figure-ground reversal if these coincident parts were of opposite colour. This is not entirely reconcilable with such a non-directional satiating process.

Cohen (1959) points out that Hochberg did not measure the rate of apparent change (RAC) of the test pattern. In a somewhat similar experiment Cohen presented a black Necker cube on a white background followed by a white Necker cube on a black background. The RAC of the second stimulus was increased by first viewing the other stimulus. This result then supports such a non-directional satiation process. This finding of the satiation of one aspect producing predominance of the other aspect in subsequent viewing of the stimulus was extended by Carlson (1953) using a 'rod and eclipse' figure in three different versions; one ambiguous and two favouring one or other of the possible interpretations. Pre-exposure to one of the biased versions did produce a favoured perception of the other aspect when tested on the ambiguous version. However, Carlson considered that this finding may have been due to a 'contra-suggestive response' as a result of the preliminary exposure. He tested this by using three versions (one ambiguous and two biased towards one or other aspect) of Boring's ambiguous figure. In this case the previous experience on a biased version led to that same interpretation of the ambiguous figure - this is in contradiction to the finding for the reversible perspective 'rod and eclipse' figure. Carlson proposed that this failure with the ambiguous figure was actually in line with a Satiation Theory explanation by arguing that Köhler and Wallach's original formulation depended upon differences in the spatial loci of the two figural aspects being tested. In Boring's figure, the two aspects do not differ in apparent spatial relations and, therefore, no effect of prior satiation to one aspect would be expected to affect that aspect any differently from the other. Carlson suggested that the meaning of such ambiguous figures was important and like Leeper (1935) concluded that 'set' or 'expectancy' was operating here. To explain how the prior experience of one aspect in this case does not lead to satiation of that aspect, Carlson proposed either that a change in the formulation of Satiation Theory was required or alternatively, that such ambiguous figures were not accountable for by this theory.

Adams and Haire (1959) demonstrated that when a smaller Necker cube was inscribed within a larger one then if they were both of the same orientation reversals of both occurred together. If they were of opposite orientation the smaller one reversed faster. They interpret this as illustrating that when they are similar the figural currents reinforce one another, there being less interaction of such currents when the two cubes are opposite.

Pelton and Solley (1968) proposed that Köhler and Wallach would predict faster acceleration of reversal rates in a condition where the subject is asked to maintain one aspect as opposed to switching aspects (i.e. voluntarily reversing) quickly. This is because in the first case the satiation of one aspect develops without any confounding effects as in the second case. Their results demonstrated faster reversals in the switching condition, thus being against the proposed Satiation Theory prediction.

Howard (1961) tried to measure the 'satiation period' of a rotating figure which had a relatively dominant aspect. This period refers to the time from first exposure of the stimulus to the initial appearance of the non-dominant aspect. In a series of experiments, largely using rotating wire cubes, he demonstrated that the cause of the reversal was central. With two cubes rotating in opposite directions and employing a central fixation point, subjects reported that they reversed together. Howard argued that it is difficult to consider the eyes to be following both rotations at the same time and so ruled out eye movements as an explanation. Binocular satiation periods were longer than the corresponding monocular ones thus supporting his argument that the alternation mechanism lies higher than the optic chiasma.

Basically, Howard proposed that the stimulus cube satiates but not in the sense of a 'volume of satiation in the cortex' as the satiating effect did not transfer to other stimuli. Rather it was a "specific movement-in-depth-cubic-pattern of satiation." Thus he argues that his results do not support Köhler's theory of non-neuronal conduction but does support the satiation concept suggesting that 'auto-inhibition' may be a better term.

1.10.4. Orbach, Ehrlich and Heath

Satiation theory was further extended as an explanatory concept by Orbach, Ehrlich and Heath (1963). These workers suggested that the concept of self-satiation although suitable for figure-ground reversible figures was not too appropriate for reversible perspective figures. In considering the Necker cube they proposed that specific parts of the figure may be selectively vulnerable to satiation, a suggestion they acknowledge to be inconsistent with Köhler and Wallach's original formulation.

Using a figural after-effects paradigm with a maintained fixation they pre-exposed one or other of the two possible 'near' faces of the Necker cube for one minute, followed by another minute's exposure of the full figure, using controlled fixation throughout. Their results only partly supported the idea that selective satiation to part of the figure would affect its subsequent appearance in the test phase. They had also predicted that if one perspective did predominate following inspection then the number of reversals in the test minute should be reduced. This again was only poorly supported.

A better explanation they then proposed was that the entire figure satiates, this being a satiation of apparent orientation. In this formulation satiation of the initial dominant percept begins rapidly and then more gradually until a threshold (taken as 100% satiation) is reached when the other aspect then becomes perceived. Satiation of the first aspect now decreases whilst that for the non-dominant aspect increases until the threshold is again reached. This process then repeats itself thus producing the reported reversals of perspective.

In this account of satiation theory a decay of satiation will occur when the figure is removed. Thus, widely spaced and brief exposures of the figure will permit satiation to decay to a minimum value after each presentation such that the threshold of reversal will never be reached and so only the dominant aspect will be reported. They proposed that this decays to near zero in some 800 ms. A faster presentation rate would cause the residual decaying of satiation to summate so eventually reaching the threshold and causing a perspective reversal.

1.10.5. Experimental Evidence

The prediction of reversal rate being related to the stimulus presentation rate was confirmed by Orbach, Ehrlich and Heath (1963) using the Necker cube - the number of reversals which were reported at various presentation rates (25 min^{-1} - 1200 min^{-1}; with various stimulus on/off ratios) depended upon the 'stimulus-off' duration. (Also found by Orbach, Zucker and Olson (1966).) Orbach and Zucker (1965) confirmed that with suitable 'time-off' periods reversal never occurred demonstrating that the growth of satiation in such conditions was prevented from reaching the critical reversal level.

In contradiction to this proposal of a faster reversal rate in more continous viewing of the stimulus, Kolers (1964) found a faster reversal rate when the Necker cube was presented at about three times a second. He suggested that Satiation Theory was inadequate to explain this.

Further work has attempted to influence the decay of satiation by using interpolated figures between the successive presentations of the reversible perspective figure. Orbach, Ehrlich and Vainstein (1963) found that interpolating a Necker cube with a similar axis of orientation to the initial Necker cube stimulus produced a shift towards the reversal rate found in continuous viewing of this stimulus, i.e. the interpolation affected the decay of satiation. These effects were also found if the inspection cube was presented to one eye and the interpolating cube to the other eye, thus presenting strong evidence that reversals are the result of some mechanism more central than the eyes themselves (at least at a level where binocular interaction can occur). Olson and Orbach (1966) have also employed parts of the Necker cube as an interpolating stimulus.

Orbach and Zucker (1964) compared the rate of apparent change of a rotating Necker cube with that of a static Necker cube, and found the former to be less, interpreting this as demonstrating that the satiation was inhibited from reaching the critical reversal level by the rotation.

Heath, Ehrlich and Orbach (1963) also demonstrated that the reversal rate of the Necker cube was affected by factors (heat, white noise and flicker) which have a'central' origin, whereas such 'peripheral' factors as luminosity of the stimulus lines or background illumination had little effect. Further evidence that the satiation effect is central in origin.

Orbach and Zucker (1964) agree that satiation of orientation occurs at a level higher than that of primary visual projection (Köhler and Wallach's proposal) and operates independently of retinal locus.

Pelton (1969) has criticised the satiation of orientation explanation as being inadequate, suggesting that the 'time-off' periods used by Orbach et al. are analogous to blinking with the reversals occurring in the 'figure-off' period and not while the stimulus is being viewed. Orbach and Olson (1969) have replied to this reasserting their view that reversals occur in the 'figure-on' time. They point out that Pelton produces no data to support his argument.

1.10.6. Price

Price (1967b), following Smith and Raygor's (1956) definition of satiation as "a reduction in the effectiveness of a stimulus with continued exposure", conceives of satiation as causing an inhibition of 'information' perception.

Accordingly, the initial perception of a stimulus becomes misperceived (i.e. the alternative aspect is reported) this then permits a rest period during which the satiation dissipates spontaneously. This is in contrast to Orbach's formulation which considers satiation to affect both aspects. Price argues that satiation mainly, or wholly, affects the initial dominant percept (P1), the non-dominant (P2) percept providing a recovery phase which is similar to Bills' (1931) concept of blocking. The P2 phase, Price argues, is thus fairly constant over time and does not decrease, unlike the P1 phase which does decrease with exposure time. Thus the overall effect of continued observation is of increasing reversal rate.

Reversible perspective figures contain both dominant (P1) cues and non dominant (P2) cues. The dominant cues provide veridical information (this also includes past experience) about the initial aspect perceived, whereas the non dominant cues, provide ambiguous or false information. The effectiveness of the dominant cues is reduced by an increment in 'conditional satiation' when a reversal occurs. This produces the decrease in P1 duration towards some asymptotic level. Price (1969, a) gives this level as being after about ten perspective reversals. The duration of the P2 phase is fairly short thus permitting negligible satiation to accrue and so the P2 time remains short and fairly constant over the observation period.

Price assumes that reversal occurs when some constant critical satiation level is reached, in this respect this is similar to Orbach's approach.

1.10.7. Experimental Evidence

Using a single Howard cube (i.e. a rotating skeletal cube, so called after Howard, 1961) and maintained fixation Price (1967,b) confirmed his predicted decrease in P1 duration and fairly constant P2 time. This finding was further extended to the Beaunis 'pile of cubes' figure (1967a). These demonstrations that the increase in reversal rate with longer viewing time are due to a decrease in P1 duration are in contradiction to the formulation of Orbach, Ehrlich and Heath (1963). According to these workers both percepts should show a decrease in duration. Price suggests that the only way to explain his results by such a formulation would be to assume either two widely different thresholds for each aspect or else that satiation develops more rapidly for one than the other aspect.

The asymptotic level of reversal rate found by Price is seriously questioned by Bruner, Postman and

and Mosteller's (1950) results. Using long observation periods with the Schröder staircase these researchers found that the reversal rate still declined well after Price's proposed asymptotic level had been reached. Subsequently Price (1969a) investigated 20 reversals of the Howard cube and found that whereas the P2 phase remained fairly constant throughout, the P1 phase declined only during the first half of the experiment, as predicted, but then began to show quite wide variations in duration. This Price attributes to problems of maintaining fixation over the course of the experiment. Similar findings of fewer reversals in later periods of the experiment are evident in the Bruner et al. study (i.e. the last 5 minutes in the ten minute observation period). In Price's experiment this effect occurs well within 4 minutes, such difference in onset of the 'breaking up' of the P1 phase, he suggests are due to the different stimuli and methodology used. His contention is that this effect is due to fluctuations in aspect duration rather than any systematic increase in duration of either phase after some time of observation.

Essentially Price supports the concept of satiation but proposes that the time series of reversals involves two different processes. Sadler and Mefferd (1970) have strongly criticised Price, arguing that his longer P1 durations were a result of his methodology which had the effect of 'setting' his subjects to favour this percept.

For instance, the initial long P1 duration on the first presentation of the stimulus is, Price argues, increased by stimulus complexity (e.g. the Beaunis figure compared to the Necker cube). However, Sadler and Mefferd point out that this initial phase actually involves several different processes for the subject as he attempts to orient himself to the experimental task which makes this first phase different to subsequent P1 phases. Price (1971) has replied by pointing out that his methodology is very different from that of Sadler and Mefferd and so it is difficult to compare the two sets of different results obtained. The latter workers obtain results more consistent with a random process than with a steady-state process as would be expected by a satiation theory. (A threshold dependent event such as satiation should occur with a certain regularity). In a rejoinder to Price (Sadler and Mefferd, 1971) they criticise him both for not fully explaining what happens in the P2 phase as well as for smoothing his data by using group averaging processes. Sadler and Mefferd's approach is considered in more detail in a later section.

1.10.8. Dornic

Dornic (1967) uses satiation as a descriptive term, having no physiological significane, for a single central process. Using a rotating wire cube he studied the stability of percept of a given alternative by suddenly removing either binocular depth cues (covering one eye) or complete optical contact with the stimulus (covering both eyes). The effectiveness of these procedures at producing an instant reversal of the percept Dornic took to represent the degree of satiation that had accrued to the present aspect, up to that instant, and hence represented a measure of the stability of that aspect. In both cases of visual occlusion, similar trends were found, the binocular situation producing a longer satiation period. Dornic thus proposed that satiation of the current percept built up to a maximum when it then 'blocked' itself and so a reversal occurred.

Thus, perspective reversals occur at some maximum of some underlying process (satiation). This is in contradiction to Künnapas (1966) who proposed that a reversal occurred when such an underlying process was at a minimum. Dornic argued that in figures where there was not an equal probability of perceiving both versions the satiation intensity was not initially at zero. To explain the increasing reversal rate found with observation of the rotating cube, Dornic's model assumed a constant satiation level which must be attained before reversal could occur and that with time the speed of satiation increased thus producing such faster reversals with longer observation periods. He also proposed a modification of this which again predicted faster reversals with time. This assumed a constant speed of satiation but with a critical satiation 'reversal level that decreased with observation time. Dornic considered that the reversal frequency must ultimately stabilise.

1.10.9. Attneave

Attneave (1971) proposes that the Gestalt principle of pragnanz, or minimum complexity, is important in the perception of such ambiguous or reversible perspective figures. He argues that "the perceptual system employs something like a Cartesian co-ordinate system to locate and describe things in space." He considered(1968) that figures such as groupings of triangles involve some relationship with such a co-ordinate system so that they appear to be multistable and makes the comparison (1971) between the multistability of a two aspect reversible perspective figure and a multibrator circuit. In this arrangement an ongoing process inhibits the other process until the latter begins to conduct. A positive feedback loop quickly makes this second process dominant and inhibits the previously active process. The feedback loop provides some stabilisation of the current percept. This cycle is then repeated.

In the visual system he supposes that fatigue or satiation of neural structures causes this reversal process to occur.

Attneave's model is thus functionally equivalent to a satiation theory approach (Murray and Ragland, 1976), although his arguments involve the matching of the visual input to more than the one schema and in this respect shares similarities with Hochberg's (1968) theory.

1.10.10. Summary

Satiation theory has undergone several changes over the years and whilst modern researchers would not accept Köhler and Wallach's original physiological explanations there still exists evidence to support some kind of satiating process at some high level of the central nervous system.

Evidence of satiation of specific neural mechanisms has been presented by Virsu (1975) using a Schröder stair figure presented in a stereogram. Initial inspection versions presented to subjects contained horizontal disparity thus favouring one or other aspect. They were then tested on a stereogram containing no disparity (i.e. 'ambiguous' version). Pre-exposure to a biased version produced less reports of that perspective when tested on the final stimulus. Virsu takes this as supporting a satiation theory approach and proposes that in this particular case satiation in disparity-specific neural mechanisms would be sufficient to induce the reversals.

Other approaches (e.g. Dornic) shy away from such possible physiological explanations.

Some work has contrasted the adequacy of the different satiation theory explanations; e.g. Cornwell (1976) compared Köhler and Wallach's predictions of the reversal rate of an incomplete Necker cube against those of Orbach et al. finding evidence supportive of the former theory.

Research into Satiation Theory has concentrated on reversible perspective figures (mainly the Necker cube) chiefly using conditions of fixation so that, in general, possible explanatory factors such as eye movements are not invoked. Satiation Theory, in one of its various guises, still remains a plausible candidate to explain the behaviour of these stimuli.

1.11. LEARNING THEORY

Learning Theory has been applied to reversible perspective figures by Ammons, Ulrich and Ammons (1959). The basic hypothesis being that with increased viewing time, reversal rate will increase. Self reward (the satisfaction of following the experimenter's instructions successfully) is seen as reinforcing the subject (S) in making a response to each percept. The S uses cues for reversal which he gradually learns to produce himself, hence producing a faster reversal rate. A similar proposal was made in an earlier paper by Ammons (1954).

Ammons et al. used Ss who had previously had up to 20 minutes practice at reversing the Necker cube and were then required to view this stimulus for ten 15 minute trials separated by either a few hours or several days. The Ss were instructed to reverse the stimulus as fast as possible and responses were recorded either verbally or on a typewriter. At the end of each trial the Ss made detailed introspective notes.

Group mean performance was found to increase over the trials from 35 to 120 reversals per 30s period. During each trial, performance rose and then declined after about 7 minutes. After correcting for the initial 'warm up' decrement Ammons et al. conclude that reminiscence occurs over the rest periods.

They proposed that Ss may use 'primary' cues, such as foveal or non-foveal spatial arrangements of figure parts, which are relevant to depth perception, and which they have learned in the course of their lives. In this experiment the Ss were highly motivated to reverse the figure as fast as possible thus the S learns to attend to critical or effective cues and then learns to produce these cues himself to elicit the appropriate perceptual response. An example of such a cue is blinking which may initially be randomly followed by a depth reversal but eventually comes to elicit the reversal.

The introspective reports indicated that the Ss had indeed found cues associated with reversal and had then learned to produce these cues themselves (e.g. blinking, defocussing, looking at particular regions).

Additional perceptual effects were also reported by the Ss, these included fragmentation of the cube.

Ammons et al. interpret fragmentation as important for a learning theory explanation of depth perception arguing that it is related to extinction:

> "unless the S makes a 'full' depth response to a cube now and then during practice (actually feels and looks at a cube), the depth perceptual response will extinguish. That is, other responses will come to be made to the drawing of the cube." (p.164).

They further point out that fragmentation can be interpreted in a Hullian type sense by assuming the S can respond to the cube with any of a number of responses (a habit family hierarchy). The particular 'cube-response' is elicited by verbal cues from the experimenter or is self-produced and this response is then strengthened by self-reward. Reactive inhibition (I_r) specific to the cube response is generated with each response made. Thus I_r accumulates over time depending upon the response frequency, and so the tendency to make this 'cube-response' weakens so that other responses (e.g. fragmentation) begin to occur.

This interpretation they point out is relatively compatible with satiation theory. Duncan (1956) had earlier reviewed the evidence on both I_r and satiation and also concluded that they were similar in many respects. These are : both develop as a consequence of afferent stimulation; both distort behaviour away from some standard; both decay rapidly when the stimulus is removed, and both develop quickly when it is presented. The main difference is that they show different rates of dissipation following a single stimulation period. Duncan negates the other difference between the two concepts in terms of satiation being a central phenomenon and I_r being peripheral (confined to the responding effector organs) as some workers had shown the latter not to be the case, hence both he argues can be considered central in origin.

1.11.1. Experimental Evidence

Little or no direct experimental testing of such a Learning Theory approach has been undertaken. However, some researchers note that the effect of practice in increasing reveral rate (Cohen, 1959; Spitz and Lipman, 1962) is not inconsistent with such a theory (Cornwell, 1976).

Price (1967,b) argued that learning theory would predict shorter duration of the initial dominant phase (P1) on spaced viewing trials than on massed trials. His results did not support this. This prediction, however, requires acceptance of Price's argument that P2 duration remains constant. Vaegen (1976), using a rotating stimulus, found that Ss reported several new and different percepts besides reversals. This he argues is difficult to reconcile with a Learning Theory approach as Ss are reporting things they have not seen before.

1.11.2. Summary

Ammons, Ulrich and Ammons (1959) fail to present a completely worked out formal theory - a failing which they themselves acknowledge. For instance they make several predictions concerning fragmentation but unfortunately do not relate these to their actual data (e.g. they fail to say when the reported fragmentation began in the course of the experiment). Many of the effects of I_r are similar to satiation, thus different researchers may simply be using different terms to refer to the same underlying process.

1.12. ALTERNATION AS A STOCHASTIC PROCESS

Following Coombs' (1952) distinction between phenotype and genotype behaviour, Künnapas (1961) investigated the 'perceptual process' (genotype) which he considered to underlie the observed fluctuations (phenotype). This underlying process he termed the 'figural process'.

Künnapas does not state whether this is physiological or psychological in nature only that the intensity of such a process is variable over time and is measurable in psychological units. The essentially stochastic nature of this process is assumed:

> "Each subject is presumed to act as though he refers his perceptions to scales of extent or degree, and his momentary responses are subjected to random variations on these scales. The judgemental variability is caused by the imperfect discrimination of stimuli..."
>
> (p.175)

The two aspects of an ambiguous or reversible figure are assumed to give rise to two conflicting processes (Künnapas, 1966) both of which have some value on a continuum of process intensity. The algebraic difference between the two separate intensities is the intensity of the resulting figural process. Assuming each of the processes varies randomly then when an appropriate stimulus is presented a large number of times the separate intensities will form a normal distribution and the normal deviate represents the intensity of the figural process.

Upon stimulus presentation this figural process is considered to grow rapidly and reach some level which is fairly constant except for a periodic variation over time. Künnapas predicts mathematically that this variation will form a sine wave. Random variation between trials will cause the sine wave to have amplitude damping over time (caused either by the two phases having a different frequency between trials which increases with time or else the dispersions accumulate from phase to phase with time).

Experimental support for this is provided by Künnapas (1966) using multisectored discs and 100 experimental trials.

Dornic (1967), as detailed earlier, (section 1.108) has argued for an underlying single process which builds up to a maximum before alternation occurs, this is in sharp contrast to Künnapas' assumption of two underlying processes with reversals occurring at the minimum point of the figural process.

In a series of experiments Mefferd and co-workers have found evidence supportive of the existence of different specific mechanisms which they propose are operative for different ambiguous and reversible figures. The contribution of such mechanisms underlying the fluctuations produces a stochastic process.

Reversible figures, such as the Necker cube or 'embedded star', they propose involve the operation of a 'near-far' apparent perspective mechanism (Mefferd and Wieland, 1968). The embedded star figure also involves a 'one object-multiple object' mechanism (apparent unity of the Gestalt) as does the Wertheimer dot display (Mefferd, 1968 a). An 'anchor-point' mechanism (Mefferd, 1968 b) is also involved in some configurations.

Sadler and Mefferd (1970) strongly criticise experimental work such as that of Price (1967b) in which data concerning time intervals of each percept duration is averaged across Ss. This they suggest produces smoothing of the curve for successive intervals. The apparent constancy of such smoothed average curves conceals the fact that they may result from either highly systematic (i.e. satiation type processes) or completely stochastic processes. By examining individual subject records theyfind high intra-subject variability in fluctuation intervals. They conclude that this randomness whilst not completely disproving a satiation theory approach does at least require its modification.

Vickers (1972a, 1972b) agrees with the proposal of an underlying stochastic process and suggests that what is involved is a cyclic decision process. He proposes that each time a decision is reached an implicit perceptual response results until this cycle produces a different result, thus causing alternation. Individual differences in alternation rate may be a result of factors such as noise in the observer's 'system', the time to make each perceptual sub-decision or the value of the observer's decision criterion.

Martin (1967, 1971) has also supported the proposition that perspective reversals are stochastically determined finding that an exponential function could be fitted to his data. Borsellino, De Marco, Allazetta, Rinesi and Bartolini (1971) using reversible perspective figures found results well matched by a two parameter gamma function.

Taylor and Aldridge (1974) with an indented plasticene surface as a stimulus also found evidence supportive of a stochastic process. They proposed a model analogous to that of Selfridge's (1959) 'Pandemonium'. The 'demons' of this model are here considered 'cells' corresponding to neural feature detectors at some hierarchical level. Each cell switches states between the two possible aspects, each individual cell having a fixed a priori probability of selecting either aspect. Every cell is individually subject to fatigue, retroactive inhibition or satiation. The overall decision depends upon all the cells. This decision is conservative so that it requires more cells to change the decision than to maintain it. The stochastic nature of the fluctuations is due to the timing relations existing between these cells.

1.12.1. Summary

These theoretical approaches concentrate upon the sequence of successive time periods of the perspective dominance of each aspect. They argue that these are randomly determined and thus contrast with a satiation theory approach which would predict systematic periods. Data exists to support this contention and has been fitted by various mathematical functions. The models range from the psychophysical decision one of Vickers to those implicating more specific neural mechanisms (e.g. Taylor and Aldridge).

Mefferd's contention of several different mechanisms operating for different stimuli produces difficulties for a satiation theory approach. Whilst Price (1971)argues that his own data, supportive of a satiation type approach, is not reconcilable with that of Mefferd, due to contrasting experimental arrangements, there remains a need for any adequate theoretical explanation to surpass such difficulties of experimental procedure.

1.13. THE THEORY OF HEBB

Hebb (1949) postulated that frequent repetition of a particular stimulation would lead to the development of a 'cell assembly'. This is a diffuse structure in various areas of the brain which is capable of acting briefly as a closed system, delivering facilitation to other cell assemblies and usually having some motor facilitation. The action of each assembly could be started either by a preceding assembly (they are conceptualised as forming open multiple chains which converge in a hierarchical fashion) or by a sensory event, or even by both. The seriation of such events with concomitant motor units constitutes a 'phase sequence.' These proposals contrast sharply with Köhler and Wallach's (1944) satiation concept of the nerve tissues as volume conductors.

Hebb draws heavily on classical neurophysiological work to demonstrate that neural reverberating circuits arranged in such closed circuits can exist. He also proposes that repetition of such circuits tends to induce cellular changes (synaptic knobs) thus adding to the subsequent stability of the circuit.

Thus a synaptic change is postulated to occur with learning - cells which are repeatedly stimulated at the same time becoming associated.

Hebb stressed the importance of motor activity (eye movements) in perception, again in contrast to a Satiation Theory approach, stating that the "neural activity leading to the motor centres before an eye movement begins, is determinate, and specific to the locus of the peripheral stimulus." He also postulated a 't-structure' which represents a 'synthesis' of the cortical units, with a conscious equivalent of perception as a distinctive whole. By this means Hebb explains how the successive input of the separate 'glances' becomes the conscious experience of the whole stimulus.

Hebb's formulation also distinguished between the 'unity' of the figure and its 'identity', the latter of which depends upon factors such as experience.

A modification to Hebb's theory was made by Milner (1957) who aimed to make the 'cell assemblies' concept more explicit. For Milner such assemblies were mainly cortical neurones and he emphasised the role of neural inhibition. In a later paper Hebb (1963) argues that the all-or-none disappearance of a stabilised image fits in with this concept of assemblies as representing distinct units of the stimulus.

To explain the 'flip-flop' action of ambiguous figures Hebb (1966) proposed that the incoming afferent impulses can set up two distinct cell assemblies which are reciprocally inhibitory (thus accepting Milner's modifications). These assemblies are conceived as lying intermingled in the same region of the brain, thus at any time either assembly (representing each possible aspect of the stimulus) may be stimulated, which inhibits the other assembly, until that in turn becomes stimulated so causing alternation. The exact cause of such fluctuation is, however, not clarified.

1.13.1. Experimental Evidence

Mefferd and Wieland (1968) found that when observers were asked to judge the size of the faces of a Necker cube then the 'near' face was judged the smaller, regardless of perspective reversals. This they interpret as indicative of a processing at different loci of the information relative to the 'near' or 'far' face. This is supportive of Hebb's formulation. Indeed physiological evidence does indicate that neural structures of some size do exist (Riggs, 1972) which process different specific aspects or 'features' of the stimulus (Hubel and Wiesel, 1962) - findings which also lend support to Hebb's theory.

1.13.2. Summary

Hebb's theory has more physiological support than such approaches as Satiation Theory. However, his point of view as regards fluctuations of perception has had no direct experimental testing as such, but several subsequent theorists (e.g. Hochberg) have built upon his foundations.

1.14. TWO MINOR THEORIES

Two theories of less importance here are due to Yacorzynski and Cowan. The former has little supportive evidence to its credit, whereas the latter gives an interesting specification of impossible figure constructions.

1.14.1. Brain Dynamism

Yacorzynski (1966) proposed a theory of brain dynamism to account for perceptual fluctuation. His initial assumption being that the alpha rhythm is evidence of an interplay of neural activity. This interplay he terms 'field forces' which he argues are affected in a number of ways by the incoming stimulation. His theoretical proposals are embraced within a few postulates which he considered represent some principles both of perception as well as of brain functioning.

Taking the Necker cube as an example of a reversible figure he proposes that parts of it (the 'front' and 'back' faces) are in equilibrium and the rest of it is in disequilibrium. It is only the latter parts he argues which contribute to the fluctuations. Field forces are proposed to act on these parts out of equilibrium so as to bring them into equilibrium, so resulting in fluctuations.

In considering the time to the first reversal Yacorzynski considers this may reflect several things; the S making sense of his perceptual experience (c.f. Sadler and Mefferd,1970), the forces may need time to build up to a point at which reversal occurs, or the S may need to decide to which parts of the stimulus to attend. The latter two alternatives being somewhat similar to Satiation Theory and McDougall's approach respectively.

The quantitative measure of frequency of reversals is criticised by Yacorzynski as this he says is not representative of the interactive forces. Instead he stresses qualitative factors which he proposes are produced by the hypothesised forces. He therefore relies heavily and exclusively upon the introspective reports by psychologically sophisticated Ss who are: "knowledgeable about the nature of the reversible figures, but not about the expected outcome predicted by the proposed hypothesis."

Yacorzynski produces little experimental evidence to support his ideas and only seldomly refers to the introspective reports of the Ss. The only experimental evidence he draws upon are studies involving brain damaged patients and their performance with reversible figures.

1.14.2. Theory of Braids

Cowan (1974, 1977) has extended the mathematical theory of braids (Artin, 1947) to describe the creation of impossible objects. He has developed a system for specifying these torus figures by distinguishing between creases and edges and also by defining types of corners. Possible and impossible figures can then be created by joining the specified corners in particular fashions as determined by braid theory.

No attempt is made here to deal with this approach in any detail.

1.15. INFORMATION PICK-UP

The theory of information pick-up stems from earlier theories of naive realism (Coren and Girgus, 1978). The Gibsons (E. J. Gibson, 1967 ; J. J. Gibson, 1950, 1968) are the prominant supporters of this view. Basically they propose that visual stimulation contains invariant properties which are in psychophysical correspondence with constant phenomenal objects (Gibson, 1951). The observer merely selectively attends to the external stimulus, thus possibly missing particular stimulus features.

With reversible and ambiguous figures the stimulus is the same but the stimulus information is not, there being counterbalanced values of such information.

Gibson (1968) states:

> "The perception is equivocal because
> what comes to the eye is equivocal"

and goes on to hypothesise that:

> "the same stimulus array coming to the eye will always afford the same perceptual experience insofar as it carries the same variables of structural information. If it also carries different or contradictory variables of information it will afford different or contradictory perceptual experiences."(p.248).

It is argued that the paradox of such figures can be resolved by analysing the stimulus information as well as appealing to subjective determining factors. The latter being considered as forms of attention.

The economy of perception is emphasised in this approach such that: "only the information required to identify an object economically tends to be picked up from a complex of stimulus information." With increasing observation time more and more information is picked up, thus the perception becomes more veridical. Sadler and Mefferd (1970) propose that Price's (1969a)results, where the duration of the veridical percept (P1) is always greater than the non-dominant (P2) percept together with some increase in P1 duration in later trials, are both consonant with this idea. This may not be entirely true however as P1 durations show wide fluctuations in duration in the later trials.

Kennedy (1974) following Gibson's work distinguishes between occluding edges and occluding bounds in line drawings. The former occurring where the line is angular and the latter where it is rounded. Both serve to separate a surface from its background. Applying these concepts to ambiguous and reversible perspective figures Kennedy argues that figures such as Rubin's 'vase-face' involve occluding bounds such that fluctuation involves reversal of the direction of occlusion. The Necker cube reversals involve both a change of occlusion as well as a change of orientation. With regard to impossible pictures he argues that the direction of occlusion changes along the length of these figures such as 'the three pronged clevis'. Kennedy suggests that information for depth or occlusion is irrelevant once reversals have begun, this information only being important in the initial phase before the first reversal.

1.15.1. Summary

This approach stresses that the observer selectively attends to parts of a stimulus which contains invariant information. It admits the role played by factors such as 'set' in affecting the resultant perception but it does not adequately handle why a reversal ever occurs. Simply stating that the stimulus information is equivocal does not fully explain why and when a fluctuation should occur. Gibson (1968) essentially conceives of attention as wandering between two alternative cognitive explanations (Mefferd, 1968a), but this really requires more elaboration to become an acceptable explanation. Kennedy himself does little more than provide a description of the fluctuations of these figures, not an adequate explanation.

1.16. PERCEPTUAL HYPOTHESES

The concept of 'unconscious inference' has been greatly extended by Gregory in several publications (1966,1970, 1973, 1974). He proposes that perception is a dynamic activity which involves forming hypotheses about (and thus 'betting on') the most probable interpretation of sensory data in terms of the world of objects. Perception is not just determined by the stimulus patterns in this formulation as Gibson (1968) would argue. Like Gibson though Gregory emphasises the ambiguity inherent in pictorial representations of real objects. The act of perception thus involves making efficient use of this ambiguous information for selecting the appropriate internally stored hypothesis about the current state of the external world. The ready alternation of ambiguous and reversible figures demonstrates that not only is there a current reigning hypothesis about the stimulus but also other more or less ready-formed hypotheses which Gregory sees as being 'plausible candidates' for the same visual stimulus. Alternation thus involves changing from one to another hypothesis.

The hypotheses about objects are conceptualised as not including certain information such as the particular distance, orientation, motion or generally the size of the observed object. Since this information is not available internally in the stored perceptual hypotheses these parameters must be set by the various depth cues using real time visual data. The sensory data is possibly subject to error, thus when an incompatibility arises between this data and the current hypothesis, the data may well be rejected in favour of maintaining the hypothesis. This can then give rise to a misinterpretation of the stimulus.

1.16.1. Summary

Gregory deals mainly with reversible perspective figures emphasising the role of size constancy. The possible contribution to perceptual alternation of processes such as eye movements is generally discounted by Gregory who argues that the ability of such stimuli to alternate when presented as stabilised images is evidence of the unimportance of such factors. Similar approaches considering perceptual hypotheses are found in the work of Bruner (1974) and Luria (1973). The approach of Gregory has much in common with that of Hebb (1949). However, whereas Hebb postulates specific neural processes Gregory tends to argue in terms of proposed software logical processes without referring directly to neural processes (Gregory, 1974).

1.17. INFORMATION PROCESSING

Simon (1967) extended the information processing approach (e.g. Newell,Shaw and Simon , 1960) to reversible perspective and impossible figures. Such an approach assumes that representations of stimuli are stored in memory in structures "isomorphic with lists and branching instructions" which are modified and stored by active cognitive processes. The fundamentally serial nature of such processes is also assumed (Miller, 1956).

Simon proposes that simple stimulus configurations (e.g. angles, lines, Gestalt 'good' forms) are detected by a scanner moving over the stimulus. Upon detecting a simple configuration the scanner then searches the rest of the stimulus elements providing them with simple interpretations in relation to this initially discovered configuration. This process continues until either an internal representation has been constructed of the whole stimulus or a contradiction encountered.

When the latter occurs the interpretation is rejected and the whole cycle begins afresh usually beginning with a different initial position of the scanner with respect to the stimulus. In explaining these 'contradicting' interpretations Simon suggests that this can result by the scanner beginning independently at two separate and disparate points on the stimulus producing an interpretation which is inconsistent when the scanner focuses in on a particular stimulus feature (e.g. a line) but which can be resolved by alternating attention between parts of the stimulus which provide unambiguous information. The scanner is considered to operate both serially and locally, a 'contradiction' occurring when the same stimulus part is reached by two separate routes giving different interpretations of this part. For the individual to maintain one percept Simon supposes that the scanning will be confined to the area of the stimulus maintaining that interpretation.

Simon's approach has much in common with Gestalt theory in that he gives operational meaning to Gestalt qualities such as 'good figure'. Thus, in explaining why a stimulus representing a hexagon complete with all its diagonals (which can be interpreted as a special case of the Necker cube) is usually perceived as the former two-dimensional object, he proposes that it is composed of "symmetrically disposed sub-figures."

Stimulus redundancy is also important as this permits efficient storage of information as descriptions of objects. This presupposes effective procedures both for identifying such objects and for describing them correctly. Thus, both stimulus size and shape constancy are subsumed under this rubric.

Simon's approach has much in common with that of Hochberg (1968) and Gibson (1950). He supports his proposals by referring to the computer simulation of perceptual processes (e.g. Kirsch, 1964). It is tempting to equate the scanner with the fovea and its 'scanning' of the stimulus with selective attention (c.f. Hebb's 'glimpses'), but this perhaps does not equate too well with Simon's proposal that such a scanner can start independently at separate points of the stimulus. He does not state what sort of area the scanner covers with each analysis of the stimulus only that it detects simple configurations. He considers these to range from angles to 'closed symmetrical forms' so perhaps the scanner can vary the area of the stimulus being examined. In stressing the sequential nature of the scanning process Simon does not explain fully how the apparent immediacy of a visual experience (c.f. Hebb's formulation which handles sequential input as well as this problem) comes about - unless the scanning is accomplished at great speed.

1.17.1. Summary

No direct experimental tests of Simon's proposals are reported. It is difficult to readily see how one could in fact do this as the theory is really a particular type of interpretation which can be applied to the available data. Thus, for instance, Flamm and Bergum (1977) point out that their results can be interpreted in line with either Simon's or Attneave's (1971) proposals.

1.18. SCHEMATIC MAPS

Hochberg (1968;1970a) has proposed an updated version of the structuralists' content analysis of form into sensations and images, using fluctuating figures in the derivation of his theory. His basic argument is that perception can be broken down into 'the input of a single glance' and the schematic map - pointing out that these are almost equivalent to the sensation and image distinction.

A schematic map is defined as: "the program of possible samplings of an extended scene, and of contingent expectancies of what will be seen as a result of these samplings." Thus, in the normal viewing of a picture the eyes alternate between fixating particular regions and making movements (largely saccadic) to bring other regions of interest onto the fovea. The information from these separate glimpses needs to be co-ordinated in order to perceive the object. This co-ordination is performed by the schematic map which becomes built up from the glimpsed information and also from previous experience. The schematic map is thus a set of expectancies. Some of these expectancies are limited both temporally and spatially whereas others are more long term expectancies. Thus, 'active' looking is required in order to perceive a form over several fixations and Hochberg (1970a)proposes that it is the plan for this looking which is stored as the schematic map and not the details of each fixation. Thus, the schematic map is both similar to Miller, Galanter and Pribram's 'plan' (1960) as well as to Hebb's (1949) phase sequences. The process of perceptual learning is seen as chiefly affecting the schematic map and not the individually glimpsed information. The 'mature observer' is proposed to have a "vocabulary of sequential visuo-motor expectancies." The schematic map is thus an encoded spatial structure of the image which Hochberg (1970a) proposes has four main features:-

1) It provides an expectation of what is contained at a distal address and provides information about what to find at such an address. The distal address refers to the real position of a point in space. In order to know what is at this distal address rotations of the eye, head and body must be taken into account. Also the map must allow for its own alteration if the expected information at that address is not found.

2) It must permit recognition of an area of the scene whether the eye has come to it by different routes or if the scene itself has moved. This both allows for the scanning eye movements of normal vision and also for 'aperture-viewing' situations. In the latter case the ability to recognise a form moved behind an aperture is related to the schematic map which integrates each glance of the stimulus through the aperture.

3) Some scene features must be stored for at least the duration of the visual inspection period. This prevents recurrent entering of data already noted when the eye refixates that area.

4) Peripheral information must be analysed such that the fovea is only brought to bear on informative areas of the stimulus. Neisser (1967) has similarly proposed that 'preattentive processes,' essentially extra-foveal, serve to delineate the stimulus information. Essentially Hochberg's theory is one of selective visual

attention such that a point on a stimulus is fixated and thus 'focally' attended to as determined by the action of the schematic map.

In Hochberg's approach both the information from a fixation and also the role of eye movements are stressed. The patterning of such movements depends upon what is currently viewed both foveally and peripherally as well as the ongoing cognitive strategies; i.e. the schematic map acts to guide the visual search pattern of the eye movements.

In the course of normal viewing of ambiguous and reversible perspective figures fluctuations occur which are probably due to several reasons such as the peripheral satiation of local depth cues. However, the main factor Hochberg argues is that 'active' looking becomes relaxed. Having encoded the stimulus (e.g. a Necker cube) into such a map the eye now 'idly, passively' looks at the figure. The features (e.g. edges, corners) are now fixated without an expectation. Either by chance or by local satiation, one or more of these features will now be encoded as consonant with the alternative map of the Necker cube. Hochberg proposes that after a short period of such 'idling' an active analogue test program will again be undertaken and if this program starts from an edge now consistent with the alternative map then reversal will occur, i.e. fluctuations occur when active looking is relaxed and attention falters.

Accordingly fluctuations ought to be under voluntary control - as long as you continue to test one map the "figure should maintain the same orientation until satiation processes wrest control from the anticipatory process."

Any theory like this which implicates eye movements has to account for the fluctuations which occur when these figures are viewed as stabilised images. Hochberg quotes the work of Zinchenko (1966) who demonstrated that in stabilised image conditions Ss still make eye movements during such fluctuations even though they can have no effect on the visual input. Hochberg argues that what is important here is the 'intention' to make an eye movement with a definite expectation, and not the actual eye movement itself.

Hochberg's approach is, therefore, not a return to the early peripheralists who stressed the role of eye movements in the perception of ambiguous and reversible figures. Rather his emphasis is upon the strategy that guides such movements. Norman and Rumelhart (1975) have likewise proposed an explanation for the fluctuation of ambiguous figures involving alternative schemas.

A somewhat similar approach to Hochberg's is that of Chiang (1976) who also proposes that each feature of the stimulus is sequentially and selectively attended to. These features are associated together in short term memory with each feature decaying. The time between the inout of successive features is thus important to the recognition of the stimulus.

Chiang argues that each feature perceived will not always give a unique representation, this depending upon both stimulus and memory factors. The aspect of an ambiguous figure reported will depend upon the features currently in short term memory. Each feature is conceived of as being either weighted towards the perception of each aspect or else weighted only towards perception of a specific aspect and representing noise to the alternative. If each feature has equal probability of belonging to each aspect then Chiang suggests that the order of features fixated and thus fed into short term memory does not affect the perception of the stimulus as the image preserves the spatial relationships of the stimulus. If the probability of which aspect is reported depends on the previous feature perceived then the order of feature-input is important and this then becomes a Markov chain. Chiang conceives of the naive observer at first randomly selecting features from the stimulus. This process then either becomes a Markov chain or follows a programmed route (Noton and Stark, 1971a).

Chiang's approach is essentially similar to Hochberg. His assumption of attaching weightings to stimulus features is accepted here but he fails to give a definition of such a feature e.g. He proposes that a large feature "may be perceived by making several pauses and memorising the shape of each sub-feature within this unit." His emphasis upon the percept reported is largely in terms of the stimulus information with no account of ongoing cognitive strategies, e.g. the conditions determining whether an observer's inspection strategy is random, Markovian, or programmed are largely ignored. By stressing foveal input information more or less exclusively he both ignores peripheral visual processing and in no way accounts for the fluctuations observed in stabilised vision.

1.18.1. Summary

Hochberg's theory of schematic maps provides a plausible account of how the separate 'glimpses' of normal vision are encompassed. The account of fluctuation as an attention failure is worthy of experimental testing which it has not received.

His emphasis on the information in the glimpse is enhanced by Chiang's concept of such information as being possibly biased towards one or other aspect of the stimulus.

1.19. OVERVIEW OF THE THEORIES

Several theoretical explanations have been proposed to account both for how the one stimulus can give rise to more than one percept of figure and also to explain the fluctuation that occurs between these possible interpretations.

The early dichotomy into whether the underlying process was of central or peripheral origin has become rather redundant. It seems likely there is some truth in both. Thus, something akin to fatigue (McDougall) or a satiation process may play a role as may more peripheral factors such as eye movements, albeit in particular situations.

McDougall's theory tends to be associated with situations investigating personality factors, an area not of main concern here. Satiation Theory has undergone many transformations and has served to stimulate much experimental work, although this has concentrated on reversible perspective figures. There appears to be some evidence to support some central process such as satiation. The very same process may well be what is referred to by the Learning Theory approach, although using different terminology. Evidence against a satiation approach is that alternation may be a stochastic process with many underlying processes and not just one.

Also contrasting with the early formulations of Satiation Theory is Hebb's theory which is important in that it has laid foundations for subsequent theories to build upon. Gibson is doubtless correct in emphasising the importance of the stimulus information but the observer does more than selectively 'picking up' such information. The observer is making 'perceptual hypotheses' about this information (Gregory). The information processing approach is reflected in Simon's proposed 'scanner' which is interesting but requires elucidation. Simon's 'scanner' concept is somewhat analogous to Hochberg's proposed schematic map. Hochberg not only emphasises the selective picking up of information from the stimulus but provides a possible explanation of the integration of such information.

Each of the theories has been considered and for each one the evidence discussed.

It is proposed here that Hochberg's theory offers a possible worthwhile approach, but one in need of experimental investigation, encompassing several points from the other theories.

1.20. SUMMARY

Figure perception has been elaborated by first considering the distinction of figure and ground and then the various types of stimuli which can give rise to a different interpretation as figure. The various theories to account for such perception have also been assessed.

It is suggested that Hochberg's theory provides a worthwhile approach from which to consider the contribution of eye movements to the perception of such stimuli.

In the next chapter the parameters that affect the perception of figure are discussed with an emphasis upon eye movements. Various points raised in the next chapter are then combined with predictions from Hochberg's theory to form experimental hypotheses which are then subsequently tested in later chapters.

CHAPTER 2

PARAMETERS AFFECTING FIGURE PERCEPTION

2.1. INTRODUCTION

In the previous chapter the several types of stimuli which can give rise to different figural interpretations were introduced and their various theoretical explanations discussed. The various parameters which have been studied with regard to the ambiguous and reversible perspective figures are now considered. Usually, investigations have been concerned with how certain variables affect the fluctuations or fluctuation rate, although some studies are more aimed at how the S's initial perception of the stimulus are determined (e.g. the effects of motivation or of prior experience).

In this chapter the main parameters studied are reviewed under the separate headings of: stimulus factors, viewing conditions, instructions and response techniques, and observer variables. This both provides the general background to and demonstrates the starting point for the work reported in this thesis. For this reason emphasis is placed upon studies invoking eye movements or attentional shifts and the discussion of the effects of prior experience leads up to the starting point for the present work.

Finally, the various points elaborated in this chapter are combined with predictions from Hochberg's theory to form specific experimental hypotheses. These are detailed together with a guide to the subsequent experimental chapters in which these hypotheses are tested.

2.2. STIMULUS FACTORS

2.2.1. Size

Following Rubin's (1915) demonstration that a smaller area of the stimulus was more likely to be perceived as figure than a larger surrounding area, several studies using sectored disc stimuli have investigated the effect of the alternate sector size on figure dominance. The sectors of smaller size are typically perceived together more often as a figure than the alternate larger sectors (Graham, 1929; Goldhamer , 1934; Oyama and Torii, 1955; Künnapas, 1957; Oyama, 1960). The orientation of such sectors appears to be relevant, sectors in the horizontal and vertical directions being perceived together as figure in preference to other sectors.

With other ambiguous and reversible perspective stimuli little work has directly investigated altering the size of one aspect, in that a change in size would usually affect both aspects whereas in the above studies it differentially affects each aspect. With the Necker cube Wieland and Mefferd (1966) demonstrated that altering the length and orientation of the diagonals did affect the reversal rate in naive Ss, the same workers later (1967) reporting with the same stimulus that although the length and inclination of the diagonals did not affect perspective dominance, the orientation of the diagonals did affect both the first aspect reported and the relative dominance time of each aspect. Earlier investigations into the effects of variations of Necker cube appearance (Ammons and Ammons, 1963) concluded that parameters such as overall size, line width and stimulus orientation had little major effect upon reversal rate. Somewhat in contrast Washburn, Mallay and Naylor (1931) demonstrated that a smaller Necker cube fluctuated more rapidly than a larger one.

Not all authors report sufficient detail to assess the angular size subtended at the observer's eye by the stimulus. Consideration of this factor is dealt with in the sections on eye movements and stabilised images.

A smaller stimulus area in reversible figure-ground stimuli is typically perceived as figure more often than the larger surrounding area, but as discussed next this can be affected by the meaningfulness of the stimulus. Altering the size of a reversible perspective stimulus has had inconclusive findings.

2.2.2. Complexity and Meaningfulness

The effect of stimulus complexity has been studied in two ways; the fluctuation rate of stimuli differing in complexity has been compared and secondly the effect of increasing the complexity of a stimulus so as to favour one particular aspect has been considered.

Using Mach's book figure and the Schröder staircase Gordon (1905) found that the more complex pattern reversed at a slower rate than the simpler one (the book figure). Donahue and Griffitts (1931) extended Gordon's findings to more stimuli only finding the same results as Gordon for the same stimuli as he had used For eight other figures (such as the Beaunis cubes, reversible tumbler and the Necker cube) increasing stimulus complexity was accompanied by an increasing reversal rate for four out of their six Ss. Similarly, Philip and Fisichelli (1945) using rotating Lissajous figures found faster reversal with more complex patterns. Also Cornwell (1976) has recently demonstrated that a normal Necker cube reversed at a faster rate than one in which only segments of the cube (a less complex stimulus) were present.

In contrast, Washburn, Reagan and Thurston (1934) reported that when instructions to hold one aspect were given then their simplest figure (a book figure) was the one whose reversal rate the Ss could most easily control voluntarily as compared to the more complex Necker cube and Schröder staircase. This demonstrated that the complex stimuli more readily gave rise to fluctuations.

Porter (1938) compared the reversal rate of several stimulus figures. It was found that the simpler figures such as Rubin's vase, Necker cube or the 'rabbit-duck' figure elicited more rapid fluctuations

Flügel (1913a) presented a series of eight versions of Mach's truncated pyramid to Ss. These pictures were in order of increasing complexity (the stimuli having progressively more details added to them which favoured one aspect). In a passive viewing condition, the results demonstrated that the "complications in the drawings possess surprisingly little power to produce the favoured perspective and to prevent a reversal." It may be that this finding of increased complexity having little effect was due to Flügel's use of darker, and thus more obvious, main outlines of the basic figure throughout the stimulus series so detracting from any effect of the additional details (Pelton, Solley and Brent, 1960). For instance Osgood (1953) has demonstrated that adding markings to Rubin's 'vase-face' figure so as to favour one aspect did increase that aspect's preponderance over the alternative.

To sum up then, studies of the effect of complexity are rather inconclusive. Complexity itself is often ill defined, and taken as a relative measure between the different stimuli used.

The meaningfulness of the stimulus for the S is also important. Dutton and Traill (1933) found that when a small enclosed stimulus area was considered as a 'cave' or some other meaningful 'hole' type of stimulus then this aided the larger surrounding area to be perceived as figure. This is also implied in Donahue and Griffitts (1931) results where the greater the definiteness of ideas in the type of stimulus then the faster was the fluctuation rate of that stimulus.

Pelton, Solley and Brent (1969) using a pattern with a central irregular dividing contour, where one half had additional pattern elements (i.e. additional complexity in one half only), found that neither complexity nor meaningfulness increased the stability of that half-pattern unless the elements were "functionally integrated with the central contour" (i.e. entered into a Gestalt of which the central contour is one constituent).

This may well extend to the effects of complexity and meaningfulness on other similar stimuli so that these effects are in terms of the Gestalt so formed. An illustration of this is found in the work of Hochberg and McAlister (1953) who measured stimulus information in terms of the number of line segments, angles and points of intersection. Using a series of Kopfermann cubes (essentially variations of the Necker cube at different angles) they found that: "the less the amount of information needed to define a given organisation as compared to the other alternatives, the more likely the figures will be so perceived." Thus the likelihood of the response to the cubes as two-dimensional objects, rather than three-dimensional ones, increased as the amount of information defining this decreased.

2.2.3. Brightness, Hue and Illumination

These three factors have usually been studied together in the same set of experiments.

Using a Rubin's cross stimulus Graham (1929) found that the brighter red cross dominated over the alternate blue cross. Unfortunately this effect was confounded by the effect of hue although Goldhamer (1934) found that decreasing brightness increased figural dominance. Oyama (1960), using a six sectored disc, found that sector dominance increased with the brightness difference between the sector and the surrounding field, also finding that dark sectors were less often seen as figure. However, Murray and Ragland (1976) showed that the darker areas of a Rubin's cross stimulus were more dominant.

Using variations of Rubin's 'vase-face' figure Harrower (1936) found that brightness itself was not important but that the brightness difference between the two parts of the stimulus affected the dominance of one as the figure. Thus, whereas a white figure was dominant on a dark grey field a black figure was dominant on a light grey field. Lindauer and Lindauer (1970) using a similar stimulus to Harrower obtained a contrary result in that the darker area favoured a figure percept.

In a study of the Necker cube Mull, Ord and Locke (1954) determined that neither illumination nor brightness contrast affected the reversal rate. Mull, Armstrong and Telfer (1956) using a Maltese cross stimulus confirmed this. Similarly, Howard (1961) studying a rotating cube found no relationship between the satiation period of the cube and a change of brightness. In contrast, with the Necker cube and three illumination levels, Cipywnyk (1959) found a faster reversal rate was caused by both the degree of illumination and also with brighter illumination. Cipywnyk (1959) has further interpreted the finding that binocular viewing produced a higher reversal rate than monocular viewing as supportive of an effect of brightness, arguing that the binocular condition resulted in greater brightness than in the monocular condition.

Coren and Komoda (1973) using a 'reversible-pipe' stimulus showed that S's judged the same stimulus area to be of different lightness before and after a reversal. In this situation the illumination did not change, instead the meaningful interpretation imposed by the S resulted in such apparent change.

Sectored disc patterns have been used to investigate the effects of hue. Graham (1929) finding no clear results, whereas Oyama (1960) demonstrated that red sectors dominated with blue sectors being least dominant. In contrast Murray and Ragland (1976) found the reverse result.

In summary controversial results have been found in the few studies of these parameters that have been undertaken. A contributing factor to this may be due to the differences between the various experimental designs employed.

2.2.4. Rotating Stimuli

Various factors affect the perspective reversals of two and three dimensional rotating stimuli. With such rotating stimuli both reversals of the direction of rotation and rapid oscillation of the rotating stimulus can occur (Howard, 1961).

Lissajous figures have been used to demonstrate that reversal rate increased with the following; the speed of rotation (Philip and Fisichelli, 1945), the pattern of complexity (Philip and Fisichelli, 1945; Fisichelli, 1947) and the axis of rotation - the horizontal axis of rotation producing more reversals than for the vertical axis (Fisichelli, 1946).

2.2.5. Stimulus Presentation

A wide range of presentations or trials have been used. Brief tachistoscopic exposures were used by Wallin (1905), Solley and Long (1958), Solley and Santos (1958), Santos, Farrow and Solley (1962), Thetford (1963). Orbach and co-workers have carried out a series of experiments, (e.g. Orbach, Ehrlich and Heath, 1963). Typically, trial lengths varied between 10s to 1 minute with some studies using 2, 10 or even 15 minutes. These have been reviewed by Price (1969b) for reversible perspective figures. Rapid intermittent presentation of stimuli has also been used (Kolers, 1964a; Ammons, Ulrich and Ammons, 1959).

Sadler and Mefferd (1970, 1971) have characterised the time scale of the perception of fluctuating stimuli as consisting of three phases. Initially, the observer orients towards the stimulus, interpreting the instructions and trying to construe the stimulus. Thus, there is usually some time before the figure first fluctuates, the S perceiving a 'preferred' aspect (c.f. Howard's (1961) satiation period and Price's (1967b) initial P1 time). This is followed by a second phase in which the fluctuations are reported. Finally, a third phase occurs in prolonged viewing where boredom, fatigue etc. can affect the S's responses. This final phase possibly accounts for the breakdown in responses noted by Price (1969a) after about 10 reversals and Bruner, Postman and Mosteller (1950) in the latter part of a 10 mins. trial.

2.2.6. Summary

The main stimulus factors which have been studied are considered above. With reversible figure-ground stimuli whether a particular stimulus area will be perceived as figure depends both on its size and that of the surrounding area, although this can be affected by stimulus complexity and the meaningfulness of the stimulus for the S. With other ambiguous and reversible perspective stimuli the factor of size typically affects both aspects so that size refers to the overall stimulus size as opposed to the size of part of the stimulus. This overall stimulus size is important especially when the possible role of eye movements is considered and this is dealt with in a later section.

Complexity and meaningfulness can affect the perception of the stimulus and seem related to the particular Gestalt being considered. Complexity is often ill defined and sometimes is only a relative measure between different stimuli. Meaningfulness can act to cause a 'set' effect and so enhance the probability of perceiving an otherwise unlikely area of the stimulus as figure. Meaningfulness is related to prior experience, a factor considered later especially for ambiguous stimuli.

The three somewhat inter-related factors of brightness, hue and illumination have tended to be studied together with inconclusive findings.

Factors affecting the perception of rotating stimuli are only dealt with briefly. The various stimulus presentation times that have been employed by different researchers are finally outlined.

In conclusion the perception of figure in a stimulus can depend upon several different stimulus factors, some of which are inter-related. Research into the exact effects of these factors has often produced inconsistent evidence. Generally reversible perspective or reversible figure-ground stimuli have been employed. The inconclusive results may partly be due to the use of different stimuli as well as different experimental arrangements.

2.3. VIEWING CONDITIONS

2.3.1. Monocular and Binocular Viewing

Binocular viewing of the stimulus is used in most studies although some have used monocular presenation (e.g. Shopland and Gregory, 1964; Axelrod and Thompson, 1962; Brown, 1955 , 1962). Of particular interest are those experiments where either the effects of both types of viewing have been compared or where Ss change from binocular to monocular viewing. The effect of simply changing the eye being used in monocular conditionshas also been investigated.

As part of Flügel's (1913a) study when Ss observed wire models of Necker's cube it was observed that "reversals could not be obtained so frequently with two eyes or maintained so long", it being easier to reverse the cube when viewing it monocularly. Individual differences in this ability were particularly noted. With a similar stimulus, Howard (1961) demonstrated an inverse relationship between binocular vision and the latency to the first reversal, this being longer for the binocular than the monocular presentation. Of interest is the finding that two of his Ss who lacked stereoscopic vision demonstrated very brief latencies (similar to those for normal monocular viewing) for this stimulus. Although Price (1967b)found no relationship between stereoscopic vision (as measured by a stereopsis test) and satiation time for a single rotating cube.

McDougall (1906) mentions an observation he made on a windmill that, when viewing it from the side, the sails of the windmill appeared to reverse in depth upon closing one eye, and reverted to normal when he again opened that eye.

Dornic (1967), following Howard, studied the stability of the apparent orientation of a rotating wire cube, which was initially viewed binocularly and then either one or both eyes were occluded for a short time. The effectiveness of these measures in producing a simultaneous reversal of the cube was taken as a measure of the stability of the percept. Completely occluding the stimulus for a short time was less effective at producing such a reversal than was the removal of the depth cues (i.e. changing from binocular to monocular viewing).

Adams (1954) used monocular viewing of a skeletal cube, observing that prior monocular experience of the cube, after it had reversed, resulted in this aspect persisting after a period of no stimulation when either the same or different eye was then subsequently used. Spitz and Lipman (1962) used various monocular and binocular viewing conditions of a Necker cube. The two monocular conditions were arranged so that an overall two minute viewing session was done with Ss either simply swapping eyes after 1 minute or else swapping both eyes and hemispheres. Switching hemispheres, and so switching cortical projection areas, affected the reversal rate whilst simply switching eyes did not. Cortical dominance was also implicated in Adams' (1954) study where an effect was found dependent upon which eye was used for the initial viewing. More reports of the reversed aspect were obtained when the right eye was initially used.

Research into the effects of monocular or binocular presentation has mainly involved reversible perspective figures. The ability of such figures to apparently reverse in depth is not related to viewing such stimuli with both eyes. In fact more reversals appear to occur in monocular viewing. Why this should be so is difficult to say, as Price (1969b) puts it "...there is room for speculation...".

When monocularly viewing these stimuli changing eyes can elicit a reversal. Completely occluding the stimulus for a short time, analagous to blinking, is also partly effective at causing a reversal.

Monocular vision would seem to be providing fewer cues to maintain the perception of one particular aspect than in binocular vision. Switching eyes monocularly may cause changes in such cues which are then more related to the alternate aspect. Such changes may then cause the alternate schema to be entertained.

2.3.2. Simultaneous Viewing of Two Reversible Stimuli

Conditions in which two reversible perspective stimuli have been simultaneously presented have been studied. The interest here is in whether such stimuli appear to reverse in the same or different orientations.

In one of Flügel's (1913a) conditions Ss fixated midway between two identical stimuli, these being either cubes or outline drawings of tables. It was found that although there was a tendency for the two stimuli to fluctuate together, there were occasions when they were reported to be in opposite phase or orientation to each other. Four out of the five Ss' records showed that the percentage of time in which the two identical stimuli were reported to be in such opposite phase to each other was less than 50% (varying between 11-43% for the cubes and 2-5% for the tables). When the same experiment was carried out using a cube and a table shown at the same time it was again demonstrated that the two simultaneously viewed stimuli could reverse independently. As Flügel puts it "it is evident that there exists on the whole a remarkable degree of independence in the behaviour of the figures, though the results obtained are irregular." In a third experiment a stereoscope was used to superimpose the two different stimuli. Once again little relationship between their perspective reversals was found. Flügel took these results as evidence against a single physiological factor such as the "Traube-Hering waves" as well as to be difficult to reconcile with an explanation invoking eye movements.

In these experiments the stimuli were each drawn on card of overall size 4.5 x 2.5 cms and viewed by a S from about 40 cms. Where the stimuli were spatially separated then the distance between each card was .25 cms. A central fixation point was used throughout. This means that the spatially separated stimuli were each less than $6.4^{\circ} \times 3.6^{\circ}$ and were separated by more than 0.35° visual angle.

Adams and Haire (1958) used double Necker cube drawings such that the two cubes were either joined together in different ways or else were separated by a small or a large gap. Ss first practised reversals with a single Necker cube before experiencing the double cube figures. They were instructed to adopt a passive attitude and to "look directly at both cubes simultaneously and not to focus their attention on one or the other." The research interest here was in the initial perception of the stimuli and significantly more than half the Ss reported the cubes looking 'down' (the lower face appearing nearer) on this occasion. Also significantly more than half the Ss reported that the cubes subsequently reversed together. Very few reports of simultaneous reversals of the two cubes appearing in different orientations were obtained and these reports were mainly for one particular stimulus where the two cubes were joined side by side. From their data the cubes were separated by a gap of either 0.2^{o} or 0.5^{o}(subtended visual angle) and the cubes themselves were approximately 2^{o} visual angle in length. Verbal reports were given by the Ss both of the initial impression as well as of the reversals under subsequent passive viewing.

In another study using one Necker cube inscribed within another Adams and Haire (1959) report that when the inscribed cube was drawn in opposite orientation to the larger cube then Ss reported faster reversals for the small one. Instructions were to:

> "observe both cubes at the same time and, when the rate of reversal had become stable, to describe the relative rates and any correspondence in the reversal of one with respect to the other." (p.297)

The large cube's face was 7.5 cms wide and that of the smaller one 2.5 cms. Unfortunately the viewing distance is not given, but if it is assumed to be that of their previous study, (91 cms) then the stimuli are approximately 4.7^0 and 1.6^0 visual angle respectively.

Howard (1961) in one condition utilised two wire cubes rotating in opposite directions either side of a fixation point, finding that reversals tended to occur together but in opposite directions. The cubes were 5.7^o visual angle in length and were separated by a centre to centre angle of approximately 10^o.

The simultaneous reversal of such stimuli in opposite directions is difficult to reconcile with a theory (e.g. the early peripheralists) stressing that an eye movement in a particular direction is related to a reversal. The size of stimuli used also tend to support this in that they are larger than the foveal area of the eye and so eye movements would be normally expected to scan the stimuli had not fixation been specified. These findings seem to suggest that such stimuli pairs are responded to as a whole. Visual attention seems important here. Kaufman and Richards (1969) have demonstrated elsewhere that fixation position and the locus of visual attention need not exactly correspond spatially. The specification of fixation does not necessarily rule out possible eye movements which may also occur. If such stimulus pairs are responded to as a whole then such eye movements or visual attention changes may possibly explain these reversals.

2.3.3. Perspective Reversals in Internally Generated Images

Perspective reversals occur when stimuli are used which result in internally generated images of three-dimensional drawings.

Haber (1969) reports an experiment where eight children who had demonstrated eidetic imagery ability were shown the Necker cube for 30s. All the children reported depth reversals of the figure during this period but later only three of them were able to report such reversals of the eidetic image of the cube. The number of reversals was less in the eidetic image, being about 4 reversals per 10s period, compared to 7 reversals in the same time during the initial viewing period. These three children had also reported three-dimensional eidetic images of other three-dimensional objects and were particularly 'good' eidetic imagers.

Hochberg (1968) reported spontaneous reversals of dot stereograms of reversible perspective figures. Julesz (1974) presents an ambiguous stereogram of an ascending and descending staircase pointing out that it takes :

> "considerable time to learn how to perceive both organisations at will. Even those who can easily master this switch in mental organisation usually have to destroy the prevailing state by blinking or waiting some time for neural adaptation." (p. 37).

The Shröder staircase has been presented as a stereogram by Virsu (1975). In a figural after-effects paradigm adaptation stereograms containing horizontal disparity such as to favour one or other aspect were used together with a test stereogram representing both aspects which had no disparity. In line with a satiation theory explanation adaptation to one aspect led to a decrease in reporting that aspect in the subsequently presented test stereogram. In this study fixation was maintained by Ss to aid fusion. Cormack and Arger (1968) have used stereograms of a Necker cube under three conditions of disparity and both with or without steady fixation. Retinal disparity was shown to mildly increase the dominance of the orientation consonant with the disparity (this being such that the upper face of the Necker cube appeared farther away) and this effect was greater without a fixation point. Retinal disparity affected the reversal rate but the presence or absence of a fixation point did not. Both Virsu and also Cormack and Arger appear from their data to have used stimuli approximately 5^{o} visual angle in length.

Kolers (1964a)investigated a phi effect of a Necker cube which was alternated with another cube so as to appear in motion, finding more reversals in this case when compared to a continuously viewed stationery Necker cube. Ss reported that the cube not only reversed at each termini but also in the central space between the two actual cube positions (where the cube never in fact appears).

It is difficult to relate perspective reversals of such phenomena directly with peripheral factors such as eye movements as the stimuli are only created higher in the visual system. This is particularly the case with the eidetic images as reversals in this case are reported in the absence of any external stimulus. Rather these studies seem to illustrate a facility for switching attention.

2.3.4. Partial Presentation of Stimuli

Experimental control of visual sampling of the stimulus has been attempted by using several partial presentation techniques.

Leeper (1935) using Boring's ambiguous figure and the 'rabbit-pirate' figure reports an attempt to determine S's perception of these stimuli through partial presentation. The stimuli were drawn on cards which were then covered by two pieces of paper leaving only a small opening approximately 0.6 cms, through which could be seen a part of the stimulus figure. The two papers were then drawn apart so that an enlarging diamond shaped view of the stimulus became visible. Leeper reports two conditions for the procedure: either snatching the paper away as quickly as possible or else the papers were slowly drawn apart (taking 2-3s to uncover the picture). For both conditions Ss fixated on the initial part of the figure: "After a fixation has been assumed... the subject continued to gaze at the picture, and described what he saw." Leeper chose initial starting positions which he considered favoured one aspect (e.g. the nose of the young woman in Boring's figure) or the other (the mouth of the old woman in the same picture). Through such control of initial fixation Leeper hoped to determine the subsequent perception but he attained inconclusive results:

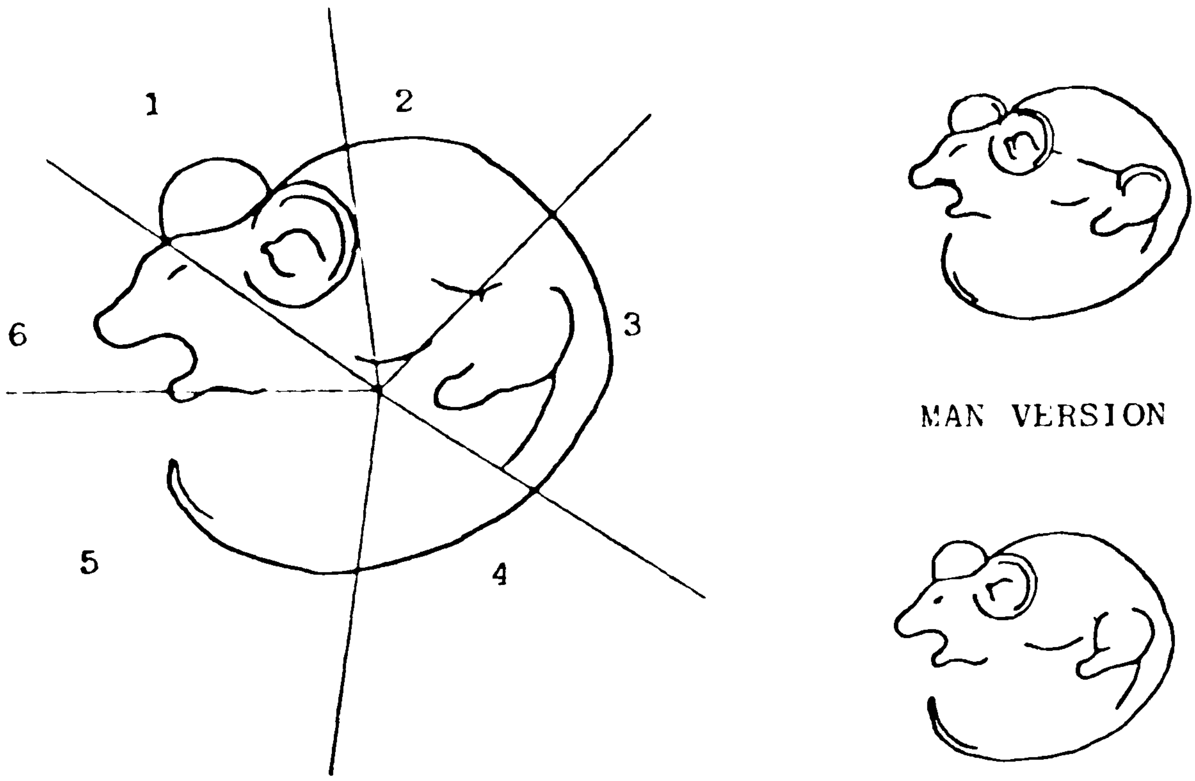
> "The slow withdrawal of the paper yielded exactly the same percentage who saw the organisation which I had not intended to favour as who saw the one I sought to bring out. With the quick jerking away, there may have been some tendency to see the picture which included as a consistent part the detail which had been fixated; but the group was too small to have any significance." (p. 70-71).

Unfortunately Leeper gives little data on this experiment, the above quotation representing his results with no information concerning picture size or viewing distance. No control of fixation position was made and the time from the initial exposure of the stimulus to the S's reporting his percept is not given. It may well be that Ss did actually scan the stimulus (particularly in the slow removal condition) before reporting. The Ss exposed to the stimuli in this fashion had no special preliminary preparation, thus this finding may to some extent reflect the naivety of the Ss.

Hochberg (1968) used Julesz-pattern dot-matrix stereograms of reversible perspective figures (Necker cube and 'bent card' figures) moved back and forth behind binocular slits. Ss viewed the stimuli through these slits and those who perceived such forms as tridimensional also reported spontaneous reversals. The width of the slits was some 3^{o} visual angle and that of the figures 18 - 20^{o}, it taking 1.5s for the stimuli to traverse behind the slits. As Hochberg points out co-ordinated tracking or binocular retinal painting can hardly explain such perception. Hochberg has greatly used the method of viewing various types of figures through an aperture in the development of his theory.

Chastain and Burnham (1975) have achieved sequential part presentation of the 'rat-man' figure in a different fashion. Two additional versions of the ambiguous figure were constructed so that each was more likely to be perceived as one or other of the possible aspects. These three stimuli were then split into segments and filmed so that in the experiment the S fixated a central mark and the stimulus picture was exposed segment by segment in correct spatial position around this point (each segment exposure was for 55.6ms, overall figure size being 4^{o} visual angle). The experimenters decided which segments most constituted a man, which most constituted a rat and which represented either. Films were then made starting with one of these segments taken from the ambiguous version followed by subsequent segments from either one of the biased versions or the ambiguous version (these are shown in Figure 2.1). After viewing the stimuli the Ss scored the figure on a 'man-rat' rating scale. Applying analysis of variance to the data no effect of bias was found but the effect of starting segment was significant in that the response was determined by this segment.

Subsequently, the man and rat starting segments taken from the ambiguous version were individually shown to Ss in a tachistoscope for the same duration as in the previous experiment. A pre-exposure fixation point was used although it is not specified if this was such that the segments were shown in the same relative spatial positions as before. Ss were initially shown geometric practice figures and then told that the next presentation



AMBIGUOUS VERSION
Divided into the 6 segments.
Starting segments: 1=man; 5=rat; 6=either.

RAT VERSION

Figure 2.1 Ambiguous and unambiguous versions of the 'Rat-Man' ambiguous figure. Chastain and Burnham (1975).

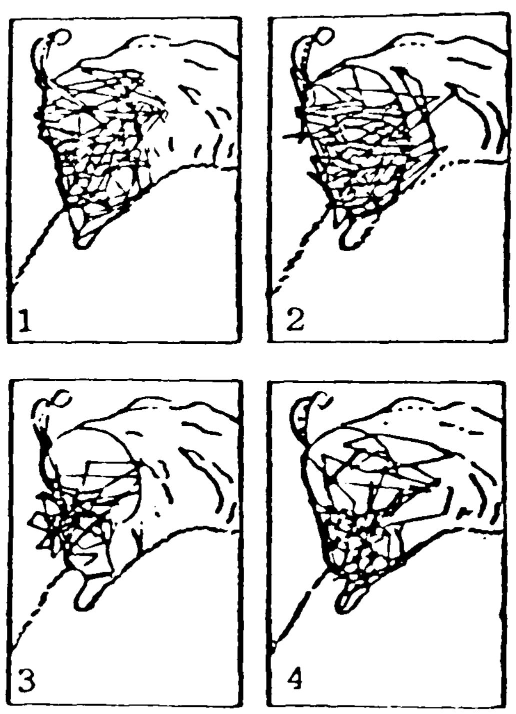


Figure 2.2 Eye movements of Ss viewing Boring's figure. Sakano (1963).

1 = Naive presentation

2 = Find both aspects

3 = Concentrate on the young woman

4 = Concentrate on the old woman

would be of a mammal. Using a similar response procedure to the previous experiment, the effect of presenting the starting segment alone was found not to be significant, both segments producing rat-like responses.

Chastain and Burnham interpret these findings as demonstrating that the initial segment serves to create a hypothesis which is then applied to the subsequent segments of the picture. Subsequent segments are necessary to elicit the two alternative perceptions as demonstrated by the failure of the second experiment to elicit both rat and man responses. This interpretation being in accord with the view of Hochberg (1968) and Neisser (1976).

Some criticisms must be made, however, of aspects of the experiment. Despite presenting the segments both in clockwise and anticlockwise fashion (finding no effect of this) the stimuli were not presented in a mirror image fashion, or in partly rotated fashion. It may be that an initial spatially distinct starting segment was influential in affecting the subsequent response, i.e. the man starting segment was always slightly above and to the left of fixation position whereas the rat starting segment was below this point.

The 6 segments seem to have been arbitrarily chosen, not being equated for size or informational content. The choice of the two biased starting segments was on the basis that the rat's 'tail' was "the most distinctive feature of the rat," the man starting segment was chosen because the nose and area slightly above it has been shown to have most value for facial recognition (Howells, 1938).

The possibility exists that the Ss who had no prior experience with the figure may have simply given a face or non-face type of response to the response scale subsequently presented (Ss were not questioned about their perceptions). That this may be the case is further evidenced by the responses of Ss shown only the single segment which when told they would be shown a mammal responded mainly rat rather than man, possibly demonstrating an influence of a prior verbal set.

The biased drawings were chosen in a preliminary experiment where Ss responded either 'rat' or 'man' to several versions of the figure. There is no evidence that the stimuli to which they responded necessarily implied that the two biased segments were all-important for the perception of each aspect. Casual observation of the two biased drawings demonstrate several additional differences outside these two segment areas, which may help perception of one aspect over the other (Figure 2.1). The exact nature of these differences and their effects would have to be known before assigning one segment as being particularly biased to an aspect.

Partial presentation methods fit in well with the theory of Hochberg. He has argued (1968) that these methods are similar to the input of the separate glances, with which we would normally view the full stimulus, which themselves take place within a schematic map. Despite the criticisms, Chastain and Burnham's (1975) work is important in showing how such maps are possibly instigated.

2.3.5. Eye Movement Recording

Direct measurement of eye movements whilst Ss viewed ambiguous and reversible perspective figures has been undertaken in order to try and establish any causal relationship between such movements and the fluctuations of the stimuli. These studies are dealt with in detail as they are pertinent to the experiments reported in subsequent chapters.

Flügel (1913a) used several reversible perspective figures to test the contribution of eye movements to their appearance. In one study Ss fixated midway between two reversible perspective stimuli (reported in section 2.3.2) finding that both figures tended to reverse together and could reverse in opposite phase to one another. This led him to discredit eye movements as a possible explanation arguing that according to such an approach the part of the stimulus fixated appeared nearer than the other parts seen in peripheral vision and so determined the reported orientation of the stimulus. Thus for such simultaneous opposite reversals two simultaneous eye movements in different directions would be required.

In another experiment on the Necker cube three Ss adopted ten different attitudes to perceiving the figure. Flügel states that the introspective reports of the Ss:

> "were strongly of the opinion that variations in the nature of eye movement and of fixation were utterly inadequate to account for the often markedly different results obtained with the different attitudes." (pp.384-385)

In what he considered a 'severe' test of an eye movement explanation he replaced the fixation point with a black square, the centre of which the Ss fixated. Using bright illumination to generate an afterimage of this square, the Ss then reported any movement in this afterimage as they viewed the stimulus. From these reports it appeared that Ss could attend to parts of the stimulus without a corresponding movement of the afterimage. Again this was taken not to substantiate a possible explanation in terms of eye movements. However, as Flügel points out the Ss were very practised before this experiment, which could affect their performance.

Flügel also tested the effects of fixation in different areas of the Necker cube whilst attention was simultaneously directed to another part. This tended to produce inhibition of the aspect attended to. This type of approach was extended to the Mach cube, Beaunis pile of cubes and a prism figure with the finding that the perspective reported depended upon which part of the figure was being attended to. For Flügel attention was equivalent to a 'clearness of consciousness', with the direction of attention being somewhat independent of eye movements and fixation.

Flügel's technique of assessing eye movement occurrence is questionable not only for its heavy reliance on introspective reports of such movements of an afterimage whilst simultaneously 'watching' for reversal, but also as Glen (1940) points out an individual's sensitivity to such movement may well vary. Direct recording of eye movements was not undertaken.

Zimmer (1913) examined the coincidence of eye movements and reversals and found that the movements occurred about a second after the reversal. Glen (1940) has commented upon the recording technique used (originally the Shackwitz method which used a pneumatic rubber device fitted to the eyelid and linked to a recording device) emphasising the point that it had elsewhere been found useful only for horizontal eye movement recording as well as having difficulty in distinguishing between eyelid movements and actual eye movements. Wallin (1905) presented evidence which he first took to represent that reversals were not initiated by eye movements (largely based on tachistoscopic work), but later (1910) concluded that the exact role of eye movements was unknown as regards reversals.

Glen (1940) used an elegant method for recording both eye and head movements, together with the Ss responses, all on the same film. He gave practised Ss five consecutive tasks, each of 1.5 mins. duration, employing a Necker cube, the face of which subtended 10^{o} visual angle. These tasks involved: passive viewing, 'driving' the reversals as rapidly as possible, inhibiting the reversals, fixating particular experimenter-determined areas of the figure, and regularly changing fixation between determined parts of the stimulus. Ss responded by pressing a key and holding it down for a reversal or temporarily holding it down for a 'partial' reversal. Glen studied the correlation between the frequency of eye movements per minute and reversals to determine any dependence. He found only low correlations and wide individual differences. The eye movements seemed to be bimodally distributed either side of the response. Glen considered that those eye movements occurring after the response may be related to the response itself rather than to the stimulus reversal. In conditions where the Ss attempted to facilitate cube reversals Ss did make more oblique eye movements. Fixating different parts of the figure had little effect on reversals, either perspective being reported at any of the predetermined fixation points. Alternating fixation between two defined points produced fewer reversals.

Glen concluded that the "evidence as a whole is conflicting" and suggested that a complexity of factors affects the relationship between reversals and eye movements. The direction of any causal relationship being not clearly established by his data. Ellis and Stark (1978) have recently pointed out that Glen neither provides spatial nor temporal information about the recorded eye movements.

Sisson (1935) using the Schröder staircase figure found 33% of the eye movements were followed by reversals and 46% of the reversals were followed by an eye movement. However, only 5.7% of all the 332 eye movements recorded were followed by a reversal within a time interval that might indicate a causal relationship. Sisson, like Zimmer, concludes that reversals are more likely to be related to central factors than to eye movements.

Using the same figure as Sisson, Pheiffer, Eure and Hamilton (1956) concluded that reversals preceded an eye movement. Three different experimental conditions were used, these being free viewing, maintained fixation and monocular viewing through a pinhole aperture. At least four reversals in each condition were examined. From the first condition Pheiffer et al., using ophthalmographic recording, found two types of eye movements: 'typical' (an erratic wandering) and 'atypical' which was less frequent and took the form of a horizontal alternation. 7.5% of all eye movements were associated with reversal and 87% of these movements were 'atypical'. Again in the pinhole aperture condition atypical movements were also associated with reversals. In the fixation condition where Ss were instructed to "look at the dot in the middle of the card" eye movements were still observed and 77.4% of these were atypical and associated with reversals. However, in this experimental condition reversals also occurred without such atypical movements and so Pheiffer et al. proposed that eye movements were not the cause of the reversals.

Pheiffer et al. used a peculiar response recording technique in this work. When the S 'saw' a reversal he tapped on his chair, whereupon the experimenter would cover one of the reflex tubes of the ophthalmograph thus producing an indication on the recording film that a reversal had occurred. They argue that the time from observing a reversal to it being indicated on the film must have been greater than 0.25s (this being the average time between an eye movement and the indication of a response from the analysed film) and, therefore, conclude that the eye movements associated with reversals follow and do not cause such reversals.

Pheiffer et al. do not give the size of the stimulus they used nor the recording resolution of their device. The atypical movements they refer to were alternating (left/right) in character.

The main criticism of Pheiffer et al.'s work must be that they do not define what exactly is meant by "associated with reversal." They conclude that when a reversal occurs an apparent shift in spatial position is noticed which:

> "instigates ocular pursuit movement ...of...decreasing amplitude as the O (observer) becomes adjusted to the new way in which the figure is perceived." (p. 454).

This would seem to be corrective eye movements of some nature. Pheiffer et al. report, but give no details of, the same finding of eye movements following reversals with other reversible perspective figures including the Necker cube.

Sakano (1963) studied both the Rubin's 'vase-face' and Boring's ambiguous figures, recording eye movements by a corneal reflection method. Ss were shown the figures in four different conditions: either no instructions at all were given (the ambiguity of the stimulus not being pointed out), the ambiguity was pointed out, or they were told to concentrate upon one or other aspect. For each condition, eye movements were recorded for 7s with the stimulus subtending an angle of some 15^{o} horizontally. Sakano noted that each condition produced different patterns of scanning. In the latter two conditions in which univocal perception was required the eye movement patterns were concentrated upon certain areas of the figure and were more systematic than in the first two conditions. The different instructions to concentrate on particular parts not only caused fixation to different positions, but also caused eye movements "of different directions." Although this is not too discernible from the data. No matter what the verbal instructions were, each S tended to fixate the stimulus in the same manner, there being wide individual differences in "peculiarities of eye movements" between the Ss. Unfortunately, his method of presenting data (see Figure 2.2) conceals both any individual differences and also the effects of the instructions upon the direction of eye movements as he plots the data of all his Ss superimposed.

Thus, in this case restricted eye movements did follow the verbal instructions to attend to a particular aspect - implicating that such eye movements at least help in maintaining that aspect of the ambiguous figure - but this data has little relevance to whether eye movements and reversals are causally related.

Mach's book figure and the Necker cube were used in a study by Holcomb, Holcomb and De La Pena (1977). Large line drawings subtending 20^{o} x 20^{o} at the S's eye were used with eye movements recorded by a corneal reflection device with an estimated accuracy of $\mp 2^{o}$. This figure was obtained for each S and was presumably recorded before the experiment or before each trial as "trials were excluded when the accuracy was less than $\mp 2^{o}$." The stimuli were divided into a 5 x 5 matrix for analysis purposes.

Ss had first been instructed that the research interest was in their pupillary responses. Three different conditions were used. The stimuli were first each presented for two 30s trials using passive instructions. In a second condition a fixation point was used and the Ss instructed to fixate this for two similar trials. For the book figure the fixation point was centrally located, whereas for the Necker cube it was located "at a three line intersection in the central region of the cube." In the final two trials Ss were asked to adopt any strategy they wished to enable them to reverse easily. In addition, a questionnaire was administered to ascertain the role of motivational style on scanning behaviour.

On the basis of the extensiveness of visual scanning or on the rate of fixations the Ss were divided into high and low scanners, these being the upper and lower 20% as determined by these measures. Both groups demonstrated a similar number of reversals. High scanners when fixating on the book figure showed fewer reversals than low scanners. The high scanners had lower reversals for the Necker cube than the low scanners although this difference did not reach significance. High scanners were characterised by alternately fixating two regions, reporting reversals at each location. In contrast the low scanning group reversed whilst fixating the same stimulus area. In the third condition the high scanners increased reversals by increased scanning, whereas the low scanners did not show such an increase. High and low scanners also had different motivational styles as measured by the questionnaire.

The authors interpret these finding as supportive of individual differences in eye movement patterns associated with the reversals which may reflect reliance on different types of selective attention as well as being affected by stimulus complexity and motivational styles.

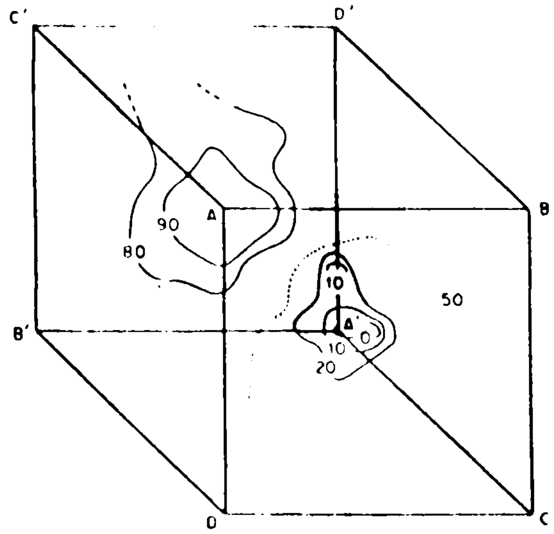
Individual differences do exist in eye movement patterns, but the pitfalls involved in this study (some of which are readily admitted by the authors) render the findings only tentative. It is not evident from the report whether the Ss were instructed as to the reversibility of the stimuli - the Necker cube can give rise to many perceptual interpretations, possibly affecting scanning behaviour. The analysis technique (dividing the stimulus into grid squares each subtending 4^{o} visual angle) is gross and may possibly conceal some of the eye movements. The failure to find a significant difference between high and low scanners on the Necker cube may be related to such a reason. The authors report no data pertinent to whether eye movements occur before, with or after a perspective reversal mentioning only that high scanners "tended to alternate fixations between two or more areas, with opposite interpretations being reported at separate locations."

Flamm and Bergum (1977) studied the Necker cube and Rubin's 'vase-face' figures. Both were outline drawings subtending 18^{o} visual angle and the eye movements were recorded by a N.A.C. Eyemark Camera. When the S noticed a reversal he pressed a key which caused a light emitting diode attached in front of the scene lens of the Eyemark to illuminate, so indicating a reversal on the recording film. After practice with the figures using instructions to observe passively each stimulus was viewed for 1.5 mins. with the S fixating a central fixation point. Individual differences in frequency of eye movements were noted. Eye movements associated with reversals were found, but showed no directional pattern with respect to these reversals. No significant difference was found between eye movements in an interval of ∓ 1s of reversal and those in intervals where no reversal was reported. 65% of the Necker cube reversals were preceded by at least one eye movement, and 55% were followed by a movement. Further, with Rubin's figure, eye movements preceded reversals in 60% of the cases and followed them in 57% of the time. These results they conclude do not support Pheiffer et al.'s. contention that eye movements follow the reversals

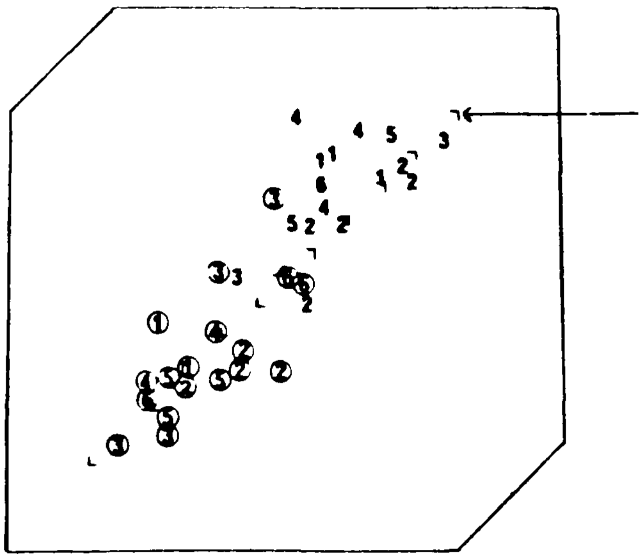
Flamm and Bergum state that "eye movements could be resolved down to approximately 5 minutes of arc from the film." This is in contradiction to the generally accepted .5 - 1^{o} resolution for corneal reflection devices (as discussed in Chapter 5). This particular technique has an even lower resolution and even when highly modified (Gale, Johnson and Worthington, 1978) it is tenuous to suggest anything better than 1^{o}. It is possible that if they accepted such a fine resolution then some of the recorded eye movements could in fact be due to very slight movements of the head-mounted camera on the subjects's head - a considerable problem with this device.

Kawabata, Yamagami and Noaki (1978) investigated both the Necker cube and Schröder staircase figures also using a corneal reflection technique. Two conditions were used, either 1 min. free viewing of the figure or a brief 200 ms exposure using a controlled fixation location in different parts of the figure. In the first condition the S's fixation positions coincided with that aspect of the cube seen both as being apparently nearer and also as figure. From the second part of the experiment Kawabata, Yamagami and Noaki produce a contour map of the fixation positions for when the lower face of the Necker cube was reported as nearer (Figure 2.3). In conclusion they point out that fixation position does affect which aspect is reported. They then explain this in terms of the processing of local depth structure within the fixation region - an interpretation consonant with that of Hochberg.

Ellis and Stark (1978) analysed the loci and duration of fixations during perspective reversals of a series of Kopfermann-like cubes (i.e. variations of the Necker cube). These stimuli (each subtending 12^{o} visual angle) were displayed on an oscilloscope and eye movements were recorded by a scleral reflection technique (resolution of 1^{o}). Ss indicated reversals by means of a three-position switch (responding as either perspective or 'neither'). Control Ss were run to check that the eye movements were not simply response related. To ascertain fixation position at the instant of reversal they assumed a response reaction time of some 400ms and



<u>Figure 2.3</u> Contour map of the rate at which the lower face (ABCD) was reported nearer. Kawabata, Yamagami and Noaki (1978).



<u>Figure 2.4</u> One S's fixation positions for the reversal of the lower left corner (circled) and the upper right corner (not circled). Ellis and Stark (1978).

then examined the fixations at that instant. They found that these fixations were longer and were not simply related to making a response. Such 'organisational' fixations, as Ellis and Stark term them, were not quite superimposed upon specific features of the cube outline as might be supposed. Great care was taken in the calibration of the recording device and so this is probably not a result of faulty recording. It is apparent from their data that the same S does not necessarily refixate the same position of the stimulus for a reversal to occur - there appears to be a range of possible positions (Figure 2.4). The organisational fixations were segregated into two clusters along the long axis of the cube figures. The longer duration of such fixations they take as representing longer processing at the time of reversal. They particularly associate the fixation (or near fixation) of one of the 'Y' shaped cube corners as being reassigned a different spatial orientation. Such a finding they argue is consonant with Noton and Stark's (1971a) scanpath hypothesis (this is discussed in Chapter 6) which emphasises a dependence between eye scanning and perception. This particular theoretical position can be considered as an extreme form of Hochberg's position and it would be more conservative to argue that these results support Hochberg's theory.

Summary. What then do such studies contribute to the debate concerning the nature of the eye movement and fluctuation relationship? It is apparent that there exists some correspondence between reversals and some type of eye movements' measure, be it fixation times, spatial location or direction of movement. An exact causal relationship, however, cannot be said to have been demonstrated. Attempts to determine the spatial location of a fixation when reversal occurs appears to demonstrate that a range of such positions occurs. Individual differences in scanning such stimuli have been reported and some Ss do use increased scanning rate to produce a higher reversal rate (Ammons, Ulrich and Ammons, 1959).

All of the eye movement recording techniques so far used have required active co-operation of the S whether it involved the wearing of a head-mounted device (Eyemark, Scleral reflection) or as for Glen a complex bench-mounted device. Similarly the stand camera used by Holcomb, Holcomb and De La Pena is also grossly obvious to the Ss. In order to ensure accuracy in their recordings the majority of researchers ran calibration trials both prior to and after the experimental trials.

It is suggested that two main criteria ought to be employed in order to adequately test a theory implicating eye movements. Firstly, the stimulus should be of such a size as to ensure scanning can occur together with concomitant registration of eye movements by the recording device with sufficient resolution to determine S's fixation location quite accurately (at least 1^{o}). The size of stimulus has to be chosen as a pay-off between being small and being large enough to facilitate such resolution of fixation location; i.e. if the stimulus is too small then eye movements may occur which cannot be resolved by the recording device, if it is too large then the exercise is self-defeating to some extent as the S will have to scan it in order to perceive it and this may not relate in any meaningful way to the perception of a smaller version of the same stimulus.

Secondly, and more importantly, the S should be unaware of the recording of his eye movements. This precludes both a pre-experimental calibration trial and most, if not all, of the previous recording methods as so far used. It is strongly suggested that by having the S aware of the recording device (either by mounting it on his head or by carefully aligning him up in some rather obvious way with recording apparatus fixed to the bench), followed by a calibration trial where S is made to fixate widely disparate areas of the visual field then this must sensitise him to the fact that the experimenter is interested in his eye movements (e.g. Ellis and Stark mention the necessity on occasions to have ' time outs' to adjust the recording device) even if some alternative explanation for such experimenter behaviour is given(few records of this have been found). It is then possible that the S makes more ocular movements than necessary. Of course, this may not be the case, but when it is theoretically important to determine an eye movement-fluctuation relationship it seems relatively unjustified to first make the S very aware of the experimenter's interest in his eye movements.

2.3.6. Stabilised Image Studies

Another approach to the study of a relationship between eye movements and fluctuations is with the use of stabilised images. Several authors (e.g. Gregory,1970; Hochberg,1970a)point out that when a Necker cube is 'viewed' as an afterimage the S still perceives fluctuations. Some workers (e.g. Gregory) conclude from this demonstration that eye movements are not related to reversals, as any eye movement taking place does not change the 'vantage point' from which the image is perceived. As already detailed in Chapter 1, Hochberg has suggested that eye movements still occur in such situations emphasising that the 'tendency' to make such a movement with a particular expectation is important and not, in this case, whether there is a resultant change in retinal stimulation.

Pritchard (1958) presented monocular stabilised images of several targets including Mach's book and Beaunis cubes using a contact lens system with a 5^{o} target size. He reports that when compared to the normal rate of reversal for such figures: "ambiguous figures show the reversals at about the usual rate provided that the S is able to direct his attention to a salient point of the pattern." Such transference of attention seemed limited to $1-2^{o}$ with the stimuli used in this study. Using Mach's figure to elucidate this point he notes that if this book figure is presented such that the top of the book is within the field of attention and S is instructed to attend to it then an increase in reversals is found. If S is instructed to attend elsewhere in the figure then a decrease in reversals is obtained. However, if the stimulus is presented such that the centre of the book figure is within his field of attention and the top and bottom of the figure are outside it then reversals tend to be prevented. Pritchard points out that the perception of such figures is affected by eye movements although the movement of the image upon the retina is not essential to observation of the reversal.

Pritchard, Heron and Hebb (1960) produced stabilised images by means of a contact lens fitted with optical attachments which included the stimulus (size 2^{o} visual angle). Using Ss quite conversant with this technique they presented a variety of stimuli. An outline drawing of a hexagon was perceived as a three dimensional cube figure which was seen to reverse in a similar fashion to the Necker cube. Another one of their stimuli was the Necker cube itself but they do not refer to its reversing in this stabilised condition. However, mention of this is made in a figure legend in another paper describing this work (Pritchard, 1961).

In this same paper Pritchard points out that a contact lens may not produce accurate stabilisation as it can slip and so produce some stimulus movement. This same point is made separately by Barlow (1963). Another approach to producing stabilised images overcoming such difficulties is by the use of afterimages.

This technique was used in a study of the effects of retinal stabilisation upon visual illusions by Evans and Marsden (1966) who created afterimages by exposing 5 cm^2 slides in front of a diffuse electronic flash with S's monocularly viewing from 38 cms away (stimuli thus subtending 7.6^{o} visual angle). Before discharging of the flash "instructions were then given to fixate a specified point on the target area." After discharge of the flash Ss closed their eyes and viewed the afterimage in this way against a diffuse flickering light - used to maintain the afterimage. Two of the stimuli used in this study were the Necker cube (all 17 Ss were able to reverse its appearance in the afterimage) and the impossible 'Devil's tuning fork' figure (all 15 Ss viewing this as an afterimage reporting that it still appeared impossible in this condition).

Evans and Marsden argue that such results demonstrate eye movements are not involved in the perception of such figures as their appearance was not affected by such stabilised viewing. It is unfortunate that they do not specify what parts of the figures the Ss were instructed to fixate, neither do they give the actual size of the stimulus figures used. The maximum visual angle of the slide was 7.6^{o} but this communicates no information about the figure size except that it was less than this.

Magnussen (1970) used both an afterimage technique and normal viewing to study the reversals of the Wheatstone cube (stimulus size 2^{o} visual angle). This is essentially the Necker cube. Stabilising the image did not prevent reversals, similar values for a group of Ss being obtained in both conditions. Magnussen thus concludes that eye movements are not relevant to the perspective reversals.

To produce an afterimage, the stimulus figure was fixated for 6 s against a high luminance background and then the stimulus afterimage was 'viewed' against a moderately-lit flickering screen, which helped to prevent rapid extinction of the afterimage.

It is difficult to believe that accurate fixation could be maintained for such a length of time which must have affected the quality of the resultant afterimage. A simpler technique for producing afterimages is to simply expose the high contrast stimulus using a photographic flashgun.

Magnussen points out that besides perspective reversals other perceptual experiences were reported including fragmentation, distortions, and fluctuations of the positive and negative phase of the afterimage.

It seems reasonable to conclude that fluctuations can occur in such stabilised image conditions. This has been taken to imply that a change of retinal information, through eye movements, is not necessary for a fluctuation to occur. In the studies considered above, eye movements were not recorded. The size of stimulus used in such studies ($2 - 5^{\circ}$) is in sharp contrast to the size used where eye movements are recorded, as discussed in the previous section. It is possible that the ability to reverse such stabilised images is related to their small size. Ss may be able to switch attention over a small stimulus (c.f. Prichard 1958) Whether eye movements are related to reversals in such small stimuli when viewed normally has not been studied. Either this ought to be done or else larger stimuli should be employed in such afterimage situations so that the two approaches can be compared meaningfully.

Eye movements have in fact been recorded during such stabilised viewing. Zinchenko and Vergiles (1972) report several stabilised image studies in which targets were attached to corneal caps in a somewhat similar apparatus to that of Pritchard, Heron and Hebb (1960). Stimuli were large and included a Necker cube picture (size 15^{o} x 15^{o} visual angle), Schröder's staircase (25^{o} x 25^{o}), and a three-dimensional Necker cube (25^{o} x 25^{o}). It is possible that the Necker cube stimuli referred to were actually Mach's 'truncated pyramid' as this is the stimulus illustrated in the article and is in accord both with the three-state S's response of "inside-flat-outside" as well as agreeing with the description of the three-dimensional construction. Eye movements were recorded during the presentation of these stimuli by means of an accelerometer attached to the corneal cap.

All Ss were able to reverse the appearance of these figures. As regards eye movements during the perception of such stimuli, Zinchenko and Vergiles state:

> "A series of psychological tests yielded facts indicating that during perception of double images, such as Rubin's well-known figures, during the perception of Necker's cube or Schroeder's staircase, and other similar objects, eye movements take place. It is postulated that successive replacement of the points of fixation leads to the reversal of such shapes. Investigation of perception of

> Necker's cube under stabilised conditions and in conjunction with the recording of ey movements showed that reversal of the cube also takes place only with changes in the positions of the eye. These results are additional confirmation of the view that eye movements under stabilisation conditions lead to switching of the receptive fields of the retina." (p. 24).

Zinchenko (1966) further points out that:

> "In spite of all the senselessness of the movements of the eye from the point of view of replacing of the image in relation to retina, they still turn out to be necessary." (p.72).

It may be that as Hochberg (1970a) has suggested the 'tendency' to make an eye movement in such stabilised conditions is important rather than whether such a movement results in a change of visual input.

2.3.7. Paralysed Eye Technique

Eye movements have also been prevented by the use of atropine to paralyse the eye muscles. Loeb (1887), with the Necker cube as stimulus, found reversals still occurred when the eye was paralysed. Loeb argued that reversals were related to accommodation and that this finding demonstrated that the efference to the ciliary muscles was the important factor. McDougall (1906) and also Wallin (1910) have criticised this interpretation. Wallin has also demonstrated that reversals can occur under atropine paralysis. George (1936) and also Zinchenko and Vergiles (1972) similarly report reversals under paralysis.

This evidence suggests that movements of the eye are not necessary for fluctuations to occur. When a S attempts to alter his direction of gaze and his extraocular muscles are paralysed then the visual field does appear to move in the direction of this attempted change (Matin, 1976). This Matin suggests reflects the 'intention' to move the eye or a shift in attention.

2.3.8. Voluntary Control of Eye Movements

Instructions to Ss to inhibit their scanning of the stimulus have been used in several studies. Lindauer and Baust (1974) and also Adams and Haire (1958) simply told their Ss to look straight at the stimulus. More specific control of eye movements has typically been with the use of a fixation mark. This is evident in work with sectored discs (e.g. Goldhamer ,1934; Künnapas, 1957; Oyama,1960) where Ss fixated the centre of the disc.

Most of the studies on the Necker cube have employed fixation. Various sizes and viewing distances have been used with the S fixating the centre of the cube; for example, Orbach, Ehrlich and Heath (1963)-8^{o}; Mull, Ord and Locke (1954)-3.17^{o}; Cipywnyk (1959)-3.6^{o}. Fixation of a specific point on the stimulus such as one of the internal Y junctions of the cube has also been used (Washburn, Malley and Naylor,1931). These latter researchers used 3 sizes of Necker cube: subtending

0.47^{o}; 4.8^{o} or 39.8^{o} at the S's eye, finding that faster reversals were reported with the smaller cube.

Fixation has also been employed with rotating reversible perspective figures (Howard, 1961; Price, 1967b) and ambiguous figures (Carlson, 1953). Flügel (1913a) reports an experiment employing two Ss with four stimuli: a reversible table outline, Mach's truncated pyramid, Beaunis pile of cubes and a wedge figure. Flügel does not give the size of the stimuli used, although they are presumably less than 6.4^{o} x 3.6^{o} visual angle - this being the size of card used in other experiments in the report. The Ss appeared to be able to fixate specified points in the figures and simultaneously attend to other areas of the stimuli.

Some studies have used both conditions of free viewing and of fixation. Cormack and Arger (1968) using a Necker cube subtending 5^{o}, viewed as a stereogram with disparity, found that the presence or absence of a fixation point did not affect the reversal rate but had an effect on the disparity such that no fixation increased the dominance of the aspect consonant with that disparity. Spitz and Lipman (1962) used a Necker cube (4^{o} visual angle), with or without Ss fixating its centre, and found little difference between these two conditions.

Voluntary fixation of a point on the stimulus display then does not prevent fluctuations although it may reduce their number. The extent to which a S suppresses eye movements in such conditions may be a fact in this, although such movements may still occur. These studies demonstrate that Ss can at least shift their attention, although whether accompanied by eye movements or not is generally not recorded. In Kawabata, Yamagami and Noaki's study (1978) eye movements were recorded whilst S fixated an internal corner of the Necker cube. Small eye movements did occur, although these appeared to be independent of the reported cube aspect. Of particular interest is the fact that the size of such stimuli is generally less than about 5^{o} visual angle, with larger stimuli exhibiting slower reversals (Washburn, Malley and Naylor, 1931). This may illustrate that the Ss facility at such attention shifting is spatially limited. This would again agree with the suggestions of Pritchard (1958) using a stabilised image of a reversible perspective figure.

2.3.9. Blinking

Although not strictly a viewing condition, blinking is included here as it is an event which has been recorded and relates to the other conditions previously considered.

Blinking by Ss was recorded by Spitz and Lipman

(1962) during both massed and spaced trials whilst Ss viewed the Necker cube, no correlation was found between reversals and such blinking. Franks and Lindahl (1963) similarly report no correlation. Brown (1962) found that, whereas blinks did appear sometimes to trigger reversals there was not a completely causal relationship as the rate of apparent change of a rotating pin pattern increased without a concommitant increase in blink rate. In Wieland and Mefferd's study (1967) some Ss used blinking as a strategy to facilitate reversals, whereas in contrast others used staring to similarly increase reversals. When Ss did not intentionally modify their blinking rates, however, the general relationship between reversals and blinking was both small and negative. Ammons, Ulrich and Ammons (1959) likewise report that Ss utilised blinking as a strategy for reversing the Necker cube, although this tended to be used by Ss exhibiting slow reversal rates.

Orbach, Ehrlich and Heath (1963) used short stimulus on and off times which Pelton (1969) argues could be equivalent to blinking with a reversal occurring within the time of the 'blink'. Although Orbach and Olson (1969) have disagreed with this interpretation. Martin (1971) has reported differential blinking during reporting of the preferred (high blink rate) and non-preferred (low rate) aspects of the Schröder staircase. Blinks tended to be associated with a reversal only when the percept changed from the preferred 'down' to the 'up' version of the figure. Reversals have been reported to occur simultaneously with the occlusion of the stimulus when viewing it with both eyes. To some extent this is equivalent to a blink.

Blinking is a strategy which the S can utilise to aid the change of stimulus aspect perceived. It functions either by providing a cessation of the current aspect stimulation or by providing a change in visual input as in a saccadic eye movement. Blinking may also relate to the state of attention so that a high blink rate indicates low attention.

2.3.10. Summary

Fluctuation of ambiguous and reversible stimuli occurs under a variety of different viewing conditions. Some of these specifically seek to eliminate eye movements by the S as a contributing factor.

Voluntary fixation by the S may not fully eliminate the possibility of such eye movements. A switching of selective visual attention may be important as with larger stimuli slower reversal rates have been reported. Stabilised image techniques do generally overcome a possible eye movement contribution, although the typically small size of the stimulus used may enable the S to selectively attend to different parts of the display. Fragmentation of such stabilised images may aid such fluctuation by altering the available cues. Where eye movements have been recorded larger stimulus displays have been used and eye movements during fluctuation found, although the exact relationship of a movement and a fluctuation has not been established. Partial presentation methods mirror the successive visual input of normal viewing without the usual eye movements occurring.

Reversals, in different orientations, of simultaneously viewed stimuli may reflect the total stimulus being regarded as a whole which reverses with changes in visual attention. When the stimuli are internally generated or the eye is paralysed the fluctuations again reflect a switching of attention. Monocular and binocular viewing differences illustrate how effective use is made of the available cues to aid the maintained perception of a particular aspect. Blinking also reflects such attentional changes.

2.4. INSTRUCTIONS AND RESPONSE TECHNIQUES

2.4.1. Instructions

Three classes of instructions are emphasised in studies of reversible perspective and ambiguous figures. These are to remain 'passive' and not to try to influence the fluctuations, this is the one most commonly used. Alternatively Ss are asked to 'hold' one aspect for as long as possible and report when it changes (e.g. Mull, Arp and Carlin, 1952) or else they are instructed to 'drive' such fluctuations as fast as possible (Bills, 1931; Ammons, Ulrich and Ammons, 1959).

Various studies have used more than the one condition: Pelton and Solley (1968) used both 'hold' and 'fast switching' instructions with the Necker cube, Eysenck (1952) used all three types of instructions with the same stimulus, and Franks and Lindahl (1963) employed both 'passive' and 'hold' conditions.

2.4.2. Response Techniques and Response Measures

Response recording is generally by two means: verbal or key press. Sometimes both are employed together or at separate times in the same study (e.g. Virsu, 1975). A single key press response has been used either with Ss responding each time a change occurs (Brown, 1955; Howard, 1961) or else pressing for one aspect and releasing for the other (Price, 1967b; Porter, 1938). Other versions of this are; a single lever moved to one side or the other to indicate each aspect (Donahue and Griffitts, 1931) and Cohen (1959) has recorded responses via a typewriter.

With a single key response a problem occurs either if the S makes an error and reports a change, such that all subsequent reports are out of phase with his perception, or when other phenomena are perceived. This latter fact was accommodated by Porter (1938) who instructed his Ss in such conditions to press the single key rapidly until the main figure aspects were again perceived.

The use of 2 keys, one for each aspect, can encompass such problems, e.g. by pressing no key (Oyama, 1960) when neither of the two aspects are perceived.

Verbal reports are also commonly used (e.g. Künnapas, 1957; Washburn, Malley and Naylor, 1931; Bills, 1931; Shopland and Gregory, 1964). Hochberg and McAlister (1953) preferred verbal reports of Kopfermann cube appearance arguing that the stimuli fluctuated too rapidly for a key press response. They also used an interesting sampling technique where S verbally reported his perceptions when a tone was presented. A similar sampling procedure was adopted by Girgus, Rock and Egatz (1977).

Both verbal and key press responses may have particular advantages in certain situations. No comparisons between the different response techniques and their possible effects upon the fluctuations of the same stimuli have been carried out. In this respect it is of interest to note that Glen (1940) considered some of the observed eye movements of his Ss could be response related. The use of a different response technique could have possibly elaborated this.

The usual response measure is that of the fluctuation rate, although the time to the first reversal ('satiation period') has been employed by Howard (1961). The aspect first reported upon presentation of a stimulus has also been commonly used (e.g. Fisher,1967a). Which measure is recorded depends upon the purpose of the investigation. Interest in which aspect is reported has involved studies of variations in appearance of the stimulus (Fisher,1967b), eye movement and fixation location at the time of fluctuation (Ellis and Stark,1978) and the effects of different types of instructions (Sakano, 1963).

2.4.3. The Problem of Multiple Perceptions

An illustration of the need for careful consideration to be given to instructions and response methods is afforded by considering the occurrence of other perceptions besides those expected by the experimenter. An inherent problem with using reversible perspective stimuli is that, unlike two-aspect ambiguous figures, they can readily give rise to more than the usually considered two percepts. Several authors report this. Ammons, Ulrich and Ammons (1959) using the Necker cube and with well-practiced Ss reversing the figure as rapidly as possible in 14 mins. trials refer to several phenomena reported. These included: "rectangle in back of square", "overlapping squares", "large diamond and border", "both faces of the cube forward at the same time." Taylor and Henning (1963) found that one naive S saw 22 forms of the Necker cube in 10 minutes when no instructions were given as regards the stimulus as having only 2 possible versions. Martin (1967) reports seeing 50 versions of a cube figure. Wong (1975) using a three-dimensional Necker cube and Schröder staircase reports increasing multiple appearances with increasing viewing distance.

With rotating figures the usual reversal reported is of direction of rotation. However, Fisichelli (1946) reports brief interruptions in good rotary motion. With a different rotating stimulus Brown (1955) found extraneous movement. Vaegan (1976) also reporting several forms being perceived for a rotating skeletal diamond shape.

This problem does not occur with two-aspect ambiguous figures, possibly due to the more meaningful interpretations accorded such stimuli which serve to limit the possible aspects. This outlines a source of difference between the two classes of stimuli and certainly emphasises the need for careful instructions with the reversible perspective figures so that the S is fully aware of the particular aspects in question. The response technique also needs to allow for such perceptions which cannot be classified as either of the expected aspects.

2.4.4. Summary

Both the instructions given to the S and the response technique employed are important factors to be considered. The instructions can affect the reported fluctuation rate and the response technique must both allow for the S making an erroneous response as well as the possibility of other perceptions besides those which the experimenter expects. The response measure employed depends on the experimental hypothesis being investigated.

2.5. OBSERVER VARIABLES

2.5.1. Observer Naivety

The problem of whether to use completely naive Ss or Ss who are aware of the possibility of more than the one percept in these figures has been considered. The difficulty with completely naive Ss is that they may report other phenomena in which the experimenter is not interested. For instance, in the case of reversible perspective figures, reports of multiple appearances of such stimuli may be reduced by first familiarising the S with the particular aspects he is to report.

Leppmann and Mefferd (1968) compared both naive and Ss who were experienced in reporting their perceptual experiences. Both groups were shown three stimuli (Necker cube, 'duck-rabbit' stimulus and then Boring's figure) to create a set to 'see' reversals and were then shown Leeper's (1935) unambiguous old woman version of Boring's figure. The naive Ss were more influenced than the experienced Ss by this procedure in that they reported more reversals with the unambiguous stimulus.

In a further experiment Mefferd, Wieland, Greenstein and Leppmann (1968) used the same stimuli but with groups of Ss who were given previous experience either on reversible stimuli, geometric stimuli or had no such pre-training. Short pre-training increased the reported fluctuations both with the subsequently presented ambiguous and unambiguous stimuli. This increase being greater for the specific training on the ambiguous than with the geometric figures.

Mefferd et al. argue that these experiments demonstrate the need to use Ss who have some experience in reporting their perceptual experiences pointing out that the latter experiment illustrates that both specific instructions and practice can influence subsequent perception. In most work Ss are first acquainted with the ambiguity of the stimulus, this may possibly distort subsequent perceptual reports. A somewhat similar point has more recently been made by Girgus, Rock and Egatz (1977) who first showed naive Ss a series of line drawings followed by two reversible figures (Rubin's vase-face and either the Necker cube or Mach's truncated pyramid). In a series of experiments, where the exposure time of the reversible stimuli was increased from 30 to 180s, about half the Ss did not report reversals. Girgus et al. argue the need for Ss to first know the alternative aspects in order for the stimulus to reverse.

Taken together these experiments illustrate the need for careful instructions regarding ambiguity or reversibility as well as consideration of the naivety of the Ss. The use of Ss who are naive with respect to the experimental hypothesis but have had some form of prior experience at perceptual reporting together with instructions elucidating the aspects of the stimuli of interest and possibly some preliminary practice at fluctuating such figures (given that this will increase the likelihood of such fluctuations) are all important factors. They also demonstrate the effects of prior experience on subsequent perception of such stimuli, a factor discussed in section 2.5.7.

2.5.2. Individual Differences

The exact nature of some parameters studied with regard to ambiguous and reversible perspective figures is complicated by several findings of individual differences between Ss. Such differences have been found for all types of stimuli, both static (Sadler and Mefferd, 1970; Ammons, Ulrich and Ammons, 1959) and rotating reversible perspective figures (Brown, 1955), reversible figure-ground patterns (Pelton, Solley and Brent, 1969) and ambiguous stimuli (Forsyth and Huber, 1976).

Wieland and Mefferd (1967) report individual differences in the strategies observers used to produce reversals such as blinking or staring (also Ammons, Ulrich and Ammons, 1959), whereas, Forsyth and Huber (1976) have characterised different 'human non-human' ambiguous figures into categories which comprise particular stimulus factors and have related these to individual differences between the Ss.

Such individual differences may be related to variables such as personality types or may reflect differences in scanning or selective attention. The existence of such differences causes problems for studies attempting to determine particular parameters affecting the fluctuations.

2.5.3. Sex, Age and Intelligence

Little work has been done on sex differences, age or intelligence effects in altering the appearance of these stimuli. The following findings tend to be reported in studies where the main interest was in other factors.

Few researchers have specifically investigated sex differences in the perception of these figures. George (1936) using McDougall's windmill, Rubin's cross and Jastrow's cube found as part of his study that women were poorer at reversing these figures than men. Sanders (1977) reports finding no sex differences in relating reversals to dogmatism. Lindauer and Baust (1974) mention a pilot study using 23 meaningful ambiguous figures and finding no sex difference either in the total number of meaningful objects reported nor in frequency of the first two responses for each figure. Lindauer (1969) using a preponderance of female subjects found no sex differences when psychology undergraduates were shown a series of versions of an ambiguous figure. Bartol and Pielstick (1972) in a study where Ss could choose which of an unambiguous version or an ambiguous version they wished to view found no effects of sex by itself, but do report a sex-age interaction.

Heath and Orbach (1963) found slower reversal rates in old people (mean age 70 years) than in young adults, equating this to the type of rate found in frontal lobe damaged patients (Yacorzynski and Davis, 1945). Their subjects all suffered from chronic dibilitating disorders of the aged and out of 31 Ss only 6 gave reliable results. Philip (1953) found no age related differences when comparing young (under 56 years) and old (over this age) groups of psychiatric patients. So too did Spivack and Levine (1959), using both normal and brain damaged female subjects in their early twenties. Holt and Matson (1976) found age changes most significant between 55 and 75 years in adults and in children between 5 and 10 years. In an earlier study (Holt and Matson, 1974) found that Necker cube reversals increased with age when children between 7 and 11 years were tested. Bartol and Pielstick (1972) report that males may have a preference for ambiguity around 12 years of age, whereas for females such preference may occur in late adolescence.

IQ effects have also been noted. Holt and Matson (1974) reported low IQ children perceiving fewer reversals. Spivack and Levine (1959), using the Necker cube and Schröder staircase, found no effect of intelligence with young adult females although Jackson (1954) found slight evidence for correlations between Necker cube reversals and scores on the Scholastic Aptitude test.

2.5.4. Personality Measures

The rate of fluctuation of reversible perspective figures has been studied with respect to the degree of introversion or extraversion of the observer. The majority of this work follows McDougall's (1929) demonstration that introverts exhibited a faster reversal rate. Subsequent work has both supported this (George, 1936; Porter, 1938; Franks and Lindahl, 1963), or found no evidence of a correlation between such personality measures and fluctuation rate (Guilford and Braly 1931; Guilford and Hunt, 1932; Guilford and Frederinsen, 1934). Sanders (1977) found a small correlation between the non recognition of ambiguity (actually the reversible perspective of a Necker cube) and dogmatism as measured on Rokeach's dogmatism scale. Newbigging (1953) studied eight reversible perspective figures and an empathy rating scale, finding that individuals exhibiting faster reversals were less accurate in their predictions of others' ratings.

2.5.5. Psychiatric Patients

Lower fluctuation rates have been reported for psychiatric patients as compared to normals (Cameron, 1936; Eysenck, 1952) with manic depressives exhibiting less reversals than schizophrenics (Eysenck, 1952; Philip, 1953; Hunt and Guilford, 1933).

Brain damaged patients exhibit slower fluctuation rates than normal Ss (Yacorzynski and Davis, 1945; McMurray, 1954 ; Spivack and Levine, 1959) as well as showing greater difficulty in ability to perceive the phenomenon (Harrower, 1939, Spitz and Blackman, 1959).

2.5.6. Motivational Effects

The effects of reward or punishment of one half of a reversible figure- ground stimulus was studied by Schafer and Murphy (1943). They used circular reversible figure-ground stimuli with a central irregular dividing line, such that each half could be perceived as a face profile (each half contained a representative eye). Separate half face profiles were first tachistoscopically exposed to the S. The S then responded with the name of the face and a number which he was led to believe controlled the choice of the next stimulus. The experimenter rewarded or punished the S for his response by adding or subtracting 2 or 4 cents from the S's amount. On subsequently testing Ss with the full circular ambiguous stimuli, when Ss had to report the name of the face, then it was found that on the first 16 of these 32 presentations the majority of the responses were in favour of the rewarded profile. Only the first 16 were analysed as by this stage Schafer and Murphy found that a new type of set had been established which functioned independently of rewards or punishments. Schafer and Murphy interpreted this result as demonstrating that autism, defined as "the organisation of cognitive processes in the direction of need satisfaction", can determine the nature of the figure-ground organisation.

Several criticisms have been made of this experiment (Pastore,1949; Solley and Murphy, 1960).

Rock and Fleck (1950) failed to substantiate Schafer and Murphy's findings in an experimental design which incorporated several modifications. Despite the 7 years between the experiments the same monetary reward of 2 or 4 cents was used. Rock and Fleck point out many of their Ss reported that this monetary amount was neither rewarding nor punishing. Jackson (1954) later used a larger amount (15 cents) and two conditions largely simulating either those of Rock and Fleck or of Schafer and Murphy. Results similar to each were obtained in the appropriate experimental condition. Thus the experimental procedure appears to affect the role of motivation. Jackson found little difference between rewarded and punished profiles and also that punished profiles were reported more frequently than neutral ones. Smith and Hochberg (1954) using Schafer and Murphy type stimuli studied the effect of an electric shock used as punishment and found that S's predominantly reported the nonshocked face as figure.

Verbal reinforcement was used by Solley and Santos (1958) in work based upon the Necker cube. Ss were reinforced for responding to an 'improved' (i.e. biased left facing or biased right facing) version of the cube and then tested on an ambiguous cube. Learning occurred, producing perceptual reports favouring the verbally rewarded version.

Age related changes occur in the effects of reward and punishment which are complicated by various factors such as punishment (a loss of money) which may actually be rewarding as it increases social interaction with the experimenter (Solley and Engel, 1960). This elaborates the fact that Schafer and Murphy's results may only be obtained under highly specific conditions (Santos and Garvin, 1962).

Evidence appears inconclusive about the effects of motivation upon the perception of a stimulus which can give rise to more than one figural area. Those effects found often appearing dependent upon the experimental conditions used.

2.5.7. Prior Experience

Rubin (1921) demonstrated the effects of prior experience on figure-ground perception in an experiment where stimuli containing an irregular area enclosed by a larger area of different colour were presented to Ss with instructions either to see the irregular areas as figure or the enclosing areas as figure. After some thirty minutes these stimuli and some new ones were randomly presented to the Ss with instructions to report whether the figure was the surrounded or surrounding area and whether this was recognised from the previous stimuli. His results demonstrated that some 64% of the figures were seen as on the previous training trials. Rubin concluded from this that there was a tendency to organise the visual field in accordance with prior experience.

Similar results were obtained by Dutton and Traill (1933) although the meaningfulness of the stimuli was also important, Gottschaldt (1929) substantiated Rubin's findings but only if the S expected a subsequent test and was set to look for familiar figures in that test. Rubin's instructions may well have led the Ss to believe their task was to look for such familiar figures. In a repeat of Rubin's experiment in which several modifications to the original methodology were made Rock and Kremen (1957) did not confirm Rubin's results. Subsequent work (Cornwell, 1963; Cornwell, 1964; Botha, 1963 ; Vetter, 1965) has generally demonstrated that prior experience can affect the subsequent perception of such reversible figure-ground stimuli.

The effects of visual or verbal prior experience were investigated in Leeper's (1935) study of the development of sensory organisation. He used two ambiguous figures, a 'rough copy' of Boring's ambiguous figure and a 'rabbit-pirate' figure. These stimuli were drawn in three ways, two biased towards one or other aspect and the other one being ambiguous. Three groups of Ss were used. One of the groups were given verbal preparation favouring one or other aspect, another group was given perceptual preparation favouring one aspect, and a final group was given no preparation. The perceptual preparation group was shown one of the biased versions of each ambiguous stimulus for thirty seconds after which Ss wrote down their descriptions of the stimulus. For the verbally prepared group, before being shown the ambiguous stimulus, a description of the biased aspect was read to the Ss. All three groups were then shown one of the composite ambiguous figures for 15 seconds after which Ss recorded descriptions of the stimulus. A second and then a third 15 seconds exposure then followed, each time allowing Ss to "record any further facts they had not noticed." Ss at this stage were then asked about the picture content. Then the ambiguous pattern was shown for 2 minutes with Ss recording when they noted the other configuration. Further assistance was given by showing Ss the biased version illustrating the version they were having difficulty with. Again the ambiguous version was then shown for 2 minutes.

Leeper found that the control group (those receiving no preliminary instructions) perceived both of the ambiguous figures in a biased fashion either favouring the young woman in Boring's figure or the pirate in the other stimulus. The majority of the Ss who had received perceptual preparation perceived in the ambiguous version that aspect to which they had been exposed in this preparation, even though there existed several differences between the two stimuli drawings (as shown in Figure 3.3). The groups given verbal descriptions of only one or other aspect produced different results with each of the two pictures. For the rabbit-pirate picture this was almost as effective as the perceptual preparation. However, with Boring's figure the results were similar to the control group for the young woman description, whereas for the old woman description a larger percentage saw the young woman than in the control group. Leeper also draws attention to the difficulty these Ss had in coming to see the other aspect in the ambiguous version, although Dember (1965) has pointed out that fine intergroup comparisons need cautious interpretation due to the design of this experiment.

The Ss were tested in groups using a projector to present the stimuli although the size of the stimuli or viewing distance is not given (another experiment using similarly projected stimuli quotes a stimulus size of 140 cms^2). The effectiveness of the prior peceptual experience for 30 seconds with an unambiguous version may well have determined the initial fixations made on the ambiguous stimuli thus helping to determine the S's response to this stimulus. In contrast mere verbal descriptions would not reliably control the initial fixation positions possibly accounting for the poorer effectiveness of this condition. A similar explanation has been offered by Chastain and Burnham (1975).

In a different experiment where individual Ss were tested on these ambiguous stimuli and then some 12 to 14 days later shown the ambiguous figure again in a completely different context (amid some slides of mental defectives) Ss did perceive the figure in the same fashion as on the first presentation. Leeper considers this finding to demonstrate not merely a case of 'set' because of the long time interval, but rather permanent habits.

Three similar versions of Boring's figure were also used by Carlson (1953). Ss first fixated for 15 s upon a biased version of the figure and then were tested on the ambiguous figure. It was found that the effect of the previous visual experience was such as to favour the perception of that aspect in the ambiguous case. Carlson does not illustrate the versions used or give the size of stimuli. He points out that whereas the 'young woman' biased version was only seen as young woman, the 'old woman' biased version was merely "favoured" as old woman with the ambiguous stimulus eliciting a general preference to perceive the young woman. This result of prior experience was, Carlson suggested, due to expectation.

Lindauer (1969) also demonstrated the effect of prior experience on subsequent perception using variations of Leeper's drawings. These were altered to produce a range of 8 stimuli; an unambiguous old woman, an unambiguous young woman, and a series of pictures of an old or a young woman. One group of Ss were shown the series starting with the young woman and ending with the old woman, another group were shown the reverse sequence. The former group elicited more young woman responses and the latter group more old woman responses.

Lindauer interpreted this as demonstrative of the effects of set established by the initial perception of the unambiguous version. In addition, one week after the experiment the two groups were unexpectedly shown one of the figures (taken from near the old woman end of the series) which were responded to as the young woman (previously they had been responded to as old woman). Only 39% of the 82 Ss in the 'young to old woman' presentation group who had originally given an old woman response to this particular stimulus now maintained this percept. In the other group 96% of the Ss now changed to a young woman response. Lindauer admits this is contrary to expectation arguing that the young Ss used may have found this a more familiar view in the absence of an immediate set.

Lindauer does not quote the size of stimulus used only that "two sequences of slides of the forms were shown to two groups of undergraduates", each form being shown for 30 seconds. He gives his ordered sequence of stimuli as being: from the young woman (W) to the old woman (M) - W, W_1, W_2, W/M_1, W/M_2, M_2, M_1, M. No explanation of the subscripts are given but if they are in order then the W/M_1 stimulus seems peculiarly labelled or out of place. No picture of the stimuli used is given only that they were based on Leeper's drawings:

> "A structural criterion of ambiguity was used to create the six ambiguous stimuli: in increasing amounts, either the W or M form contained elements of the other form; and in decreasing amounts, elements of the original form, e.g. the mouth-line of M became longer until it was the necklace of W, and the neckline of W gradually turned into the chin of M." (p. 911).

The implicit supposition is thus made that

Lindauer or his artist know what 'elements' of the picture to gradually change from W to M aspects. This may well have been based upon consideration of what constituted Leeper's young and old woman unambiguous versions, but these in fact differ in a wide variety of ways and it would be difficult to state exactly and in what order (so as to produce increasingly biased perception of one or other aspect) these should occur in such serially presented stimuli. Lindauer found that the M response was more persistent in the series starting with the old woman than that starting with the young woman pointing out that this also occurred "for specific forms." These being stimuli W to W_2 which:

> "received more M and less W responses than expected in the M-W (old-young woman) group while the reverse effect was shown in the opposite group..."
>
> ..."this also tended to be true of the response to the unambiguous M form." (p. 912).

Lindauer points out that:

> "a question then may be raised as to whether the responses of the groups were to some extent due to the nature of the stimuli rather than the result of the set" (p. 913).

considering that an unequal degree of ambiguity among the forms may account for the poor W effects. Certainly it would seem that the results of the W forms, as represented by W to W_2 would support this idea.

The Ss were able to verbally respond not only as young or old woman but could also respond as neither. If both aspects were seen they were instructed to report the first aspect noticed. Assuming the Ss were naive to the series of pictures and given that they were specifically instructed that they were to be shown a "series of pictures containing either an old or young woman" then a question must be raised about the effects of prior experience in this experiment as 72% of the responses representing inability to label the forms (these being only 7% of the total responses) occurred among the middle forms W_2 to M_2, i.e. after 2 relatively unambiguous versions had been observed. Such a failure of prior experience may represent stimulus problems rather than interpretation problems by the Ss. This is further suggested by considering the evidence of Bugelski and Alampay (1961) that the interpretation afforded an ambiguous figure can be largely determined by a preceding single set-inducing picture.

In a series of experiments Epstein and Rock (1960) further extended Leeper's work. Again they used three versions of Boring's figure (these are not represented in the article, but may well be those illustrated by Neisser, 1967), as well as Schafer and Murphy (1943) type figures. Their aim was to set up situations in which expectancy was pitted against recency and frequency. This was achieved by instructing a S that he would be shown a series of four stimuli, three of which would be A and one of which would be B, but instead was shown the series A, A, A, A/B (ambiguous A and B version). In this situation expectancy would predict that the S would perceive B, whereas recency and frequency would predict that A would be perceived.

The stimuli were exposed for 0.5s except for the ambiguous stimuli when an exposure of 0.2s was used to reduce the possible occurrence of both responses. In their first experiment 72% of the responses were in accord with a frequency/recency hypothesis and 28% were as would be predicted by expectancy. Further experiments elaborated the major role of recency as against expectancy or frequency for determining the subsequent perception of an ambiguous version of a previously presented picture. This is similar to Leeper's (1935) finding of prior verbal instructions (expectancy) having little effect compared to prior visual experience (recency).

Bruner and Minturn (1955) used a similar paradigm to Epstein and Rock, by showing either four numbers or four letters followed by '13'. Ss either perceived this as the number 13 in the former case or as the letter B in the latter condition. This was interpreted as demonstrating the effects of set affecting the degree of closure of the stimulus although it could also be interpreted as illustrating the effects of perceptual recency. Bruner and Potter (1964) further demonstrated the effect of perceptual prior experience by showing that recognition of a picture was slowed by first showing it out of focus and then gradually bringing it into focus. Alternatively, when a picture was first shown properly focussed and then defocussed it was possible to maintain the previous perception for some time.

Epstein and De Shazo (1961) confirmed the effects of recency using Schafer and Murphy type figures. They hypothesised that in the Epstein and Rock experiments, prior to the appearance of the response to the ambiguous stimulus, there occurred a period of rapid perceptual oscillation during which:

> .."the various organised alternatives appear and memory trace selection occurs on the basis of distinctive similarity. Once the trace is selected, it can then enter into the labile process and determine its further development,"
> (p.223)

This was tested in an experiment in which a galvanic skin response (GSR) was first conditioned to one aspect. The ambiguous composite stimulus was then presented under circumstances favouring a recency effect of the other alternative, i.e. it was preceded by the other aspect. Thus, according to their hypothesis the recency alternative should be perceived, but also a GSR noted. Their results showed that 38.9% of their Ss who gave the recency response did so accompanied by a conditioned GSR . They conclude that this low percentage is as would be predicted by assuming such rapid oscillation occurs, i.e. during the rapid oscillation the recency alternative would first appear for some Ss, whereas for others the alternative aspect would appear and then be replaced by the recency one. The GSR only appearing for the latter Ss.

36 of their Ss perceived the most recent aspect and 9 the non-recent. However, 15 saw both, these Ss were excluded from the percentage figure given above. This 'both' response was attained for the ambiguous stimuli which were only exposed for 0.01 seconds.

Farrow and Santos (1962) have criticised both Epstein and Rock and also Epstein and De Shazo's work arguing that their recency effects may be due to the particular procedural factors they employed. To support this they cite the work of Solly and Santos (1958) who used the Necker cube in 'biased' versions as well as its usual form. When the data of this experiment was construed in terms of recency versus non-recency effects then it demonstrated an almost equal division of evidence such that from their first test trial 103 responses were as would be predicted by recency and 122 responses by non-recency. They further quote unpublished work by Santos which again gave virtually the same distribution for recency and non-recency results.

Further points must be made of Epstein and Rock's work. In the first experiment, out of the 40 Ss used with the Schafer and Murphy figures, 17 were excluded from the data because "the situation failed to induce an unambiguous expectancy or because their responses were equivocal." Out of the 40 Ss exposed to Boring's figure 12 Ss were excluded for similar reasons. This means that 36.25% of the total number of Ss were excluded from the analysis, although their results table indicates that all 80 Ss' data was used. This is somewhat inconsistent.

Furthermore, despite the ambiguous versions only being presented for 0,25s both types of picture received a small proportion of 'both-aspects' response. These numbers being only 2 for Boring's figure and 9 for the Schafer and Murphy figure. The occurrence of a 'both' response is particularly interesting in such a short presentation time. The pre-experimental instructions gave no reason for Ss to expect a possible ambiguous stimulus which could be interpreted either way, thus a 'both' response must to some extent, besides an expectancy or recency effect, be governed by the physical similarity of the ambiguous to the non-ambiguous forms.

A projection tachistoscope was used to present the stimuli, with no control of fixation, thus, the initial fixation position could also possibly affect which aspect was first reported. This is particularly so for Schafer and Murphy type stimuli where the ambiguous figure is a horizontal composite of a left-hand and a right-hand possible figure. Thus fixating to the left or right of the centre of the stimulus presented is very likely to determine the first response. A response of 'both aspects' could be due to fixation position in combination with the ambiguous form being a composite.

The two aspects of Boring's figure are not so grossly spatially separated and so the initial fixation position would not be expected to have as great an effect. Also the ambiguous form is not the additive composite of the two unambiguous forms. These factors together may account for the lower number of the 'both aspects' responses to this figure.

In Epstein and De Shazo's experiment, ambiguous Schafer and Murphy profiles elicited a 'both aspects' response for 15 out of 60 Ss (25%) despite a tachistoscopic exposure time to prevent such 'both' responses of 0.01 s. Fixation position again was not controlled, stimuli being presented by a projection tachistoscope. A viewing distance of 45 cms was used but no further information is given about the visual size of the stimuli. Similar 'both' responses were reported in other experiments of Epstein and Rock (1960).

Bugelski and Alampay (1961) demonstrated that sets are easily established and not easily broken by using an ambiguous 'rat-man' figure. This was presented after a variable number of either human or animal drawings. Apparently only a "slight hint" needs to be given to induce a subsequent perception in that when the ambiguous figure was preceded by only one picture of either a cat or a lady then 75% of the Ss reported that the ambiguous picture was of a rat or a man respectively. When Ss were subsequently shown the ambiguous figure again after an intervening series of pictures depicting the opposite aspect then this second aspect was readily adopted if only 1 or 2 set-inducing stimuli had been used in the first phase. Although, in most cases there was not a significant loss of the original set. This demonstrates that sets are easily established and not easily broken. However, Forsyth and Huber

(1976) have demonstrated individual differences with such 'human non-human' ambiguous figures including the 'rat-man' figure and so care may be needed in using this figure to examine the effects of prior experience.

To sum up then, prior experience can affect the subsequent perception of figure in a subsequently presented stimulus. Prior visual experience being better than prior verbal descriptions. Whether the effect of such visual experience is due to expectancy, recency or frequency of the prior presentations has been investigated. Results suggest that the most recently presented alternative will be perceived in a subsequently viewed stimulus which can give rise to this or another alternative. The occurrence of a 'both aspects' response to the subsequently presented ambiguous stimulus is considered interesting as it would seem dependent on both the initial fixation position of the S on this stimulus together with the degree of similarity between this and the 'prior experience' stimuli.

The point elaborated here is the need to carefully understand the exact nature of the differences between such stimuli before they are used in this type of work. To this extent the comments made are proposed as modifiers such that prior experience may be effective for particular Ss in particular situations.

2.5.8. Summary

Observer variables are important in how stimuli which can give rise to more than one interpretation are perceived. The observer naivety together with the instructions given by the experimenter can affect whether more than the one possible aspect is elicited for the same stimulus. Individual differences exist between Ss in the perception of such stimuli. These may reflect various factors such as age, sex, intelligence, or personality differences.

The motivation of the observer may well be important but investigations are inconclusive about its effects. Prior experience of the observer with the same or similar stimuli does affect the subsequent perception of a stimulus. The point has been elaborated that the similarity of such stimuli as well as knowing where the S is looking on the stimulus is important,

2.6. A BRIEF SYNOPSIS

The perception of figure in a stimulus depends upon several factors, Some of these are parameters which are pertinent to the stimulus display such as the size of the possible alternate figure areas, complexity or hue of the stimulus. Both the instructions and response techniques used can also affect whether fluctuations of the stimulus appearance are appropriately reported.

The size of the display itself is important as to whether eye movements play any part in the reported fluctuation of the stimulus. Various viewing conditions have been utilised which either affect the available cues to each aspect or else seek to record or eliminate eye movements during viewing. Eye movements may play a role and evidence indicates that selective visual attention is certainly important. It is suggested that the possible role of eye movements has not been adequately investigated.

Various observer variables have been studied. The most interesting is the possible role of prior experience. In studies investigating this factor, variations in the stimulus display have been employed. The exact nature of how such variations are or are not effective in altering the subsequent perception of a stimulus as one or other possible aspect has not been elaborated by previous work. Eye movements have not been recorded in such situations. It is proposed that such movements or attention changes together with the particular variations employed are important parameters affecting such prior experience research.

2.7. VARIATIONS OF AMBIGUOUS FIGURES

In the previous discussion of the 'prior experience' studies it was suggested that the exact nature of the differences between the biased and ambiguous versions of an ambiguous figure could possibly affect the results of such experience. Some workers have constructed several versions of the same ambiguous figure. This is now considered.

Fisher (1968a,b) was interested in the commonly made assumption that the two aspects in an ambiguous figure are alleged to have an equal probability of being perceived 'figure' by a subject. He devised numerous ambiguous figures, drawing these in several versions so as to appear biased towards one or other of the two possible aspects. In this way for each stimulus figure 10 drawings increasingly emphasised one aspect and 10 increasingly represented the other. Fisher then subjected these 20 versions of the same stimulus to a group of 20 Ss who were "sophisticated in the sense of having been made fully aware of the purpose of the study." These Ss were asked to select both a central ambiguous stimulus and 7 versions each side of this "graded in such a way that the difference between each adjacent pair was approximately the same." Fisher then presented the selected 15 to 200 individuals and determined the number of responses indicating the first-named aspect which were reported. By this means he arrived at a version of the stimulus figure which was 'equi-probable' (i.e. judged ambiguous by these latter Ss).

The responses obtained for 8 such stimuli are shown in Figure 2.5 . What is evident is that there is firstly no markedly smooth transition from each of the versions to the next in the same series. This is in contrast to Fisher's initial selection procedure which was to obtain an equally spaced series. Secondly, it is also evident that some versions of the same figure appear to be misplaced in the series.

Fisher adopted the criterion of determining the 'ambiguous' version by ascertaining if the responses lay between $\mp$ 2 standard deviations of the sampling distribution mean. By doing this he only found one of the cases where version 8 (i.e. the version initially chosen by the sophisticated Ss) was judged ambiguous by the other Ss. For 4 of the stimuli version 7 was so judged and for 3 other stimuli versions 5, 8 and 9 were each chosen. For the 'chalice-face' stimulus no version met this criterion of ambiguity.

The generality of these latter judgements is possibly enhanced by Bartol and Pielstick (1972) who quote unpublished work using 5 of Fisher's

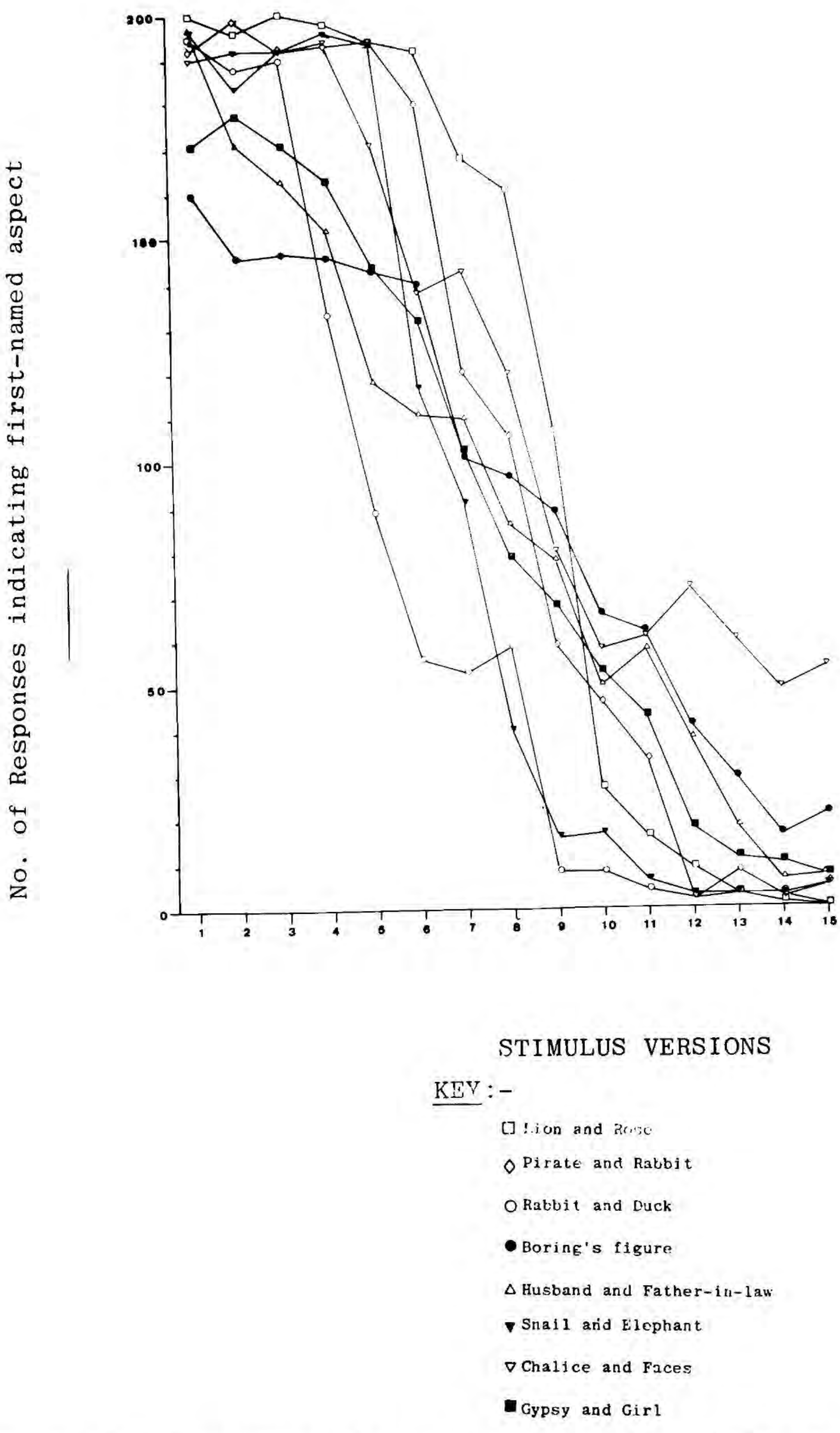


Figure 2.5 The number of occasions when the first-named aspect of 8 ambiguous figures was first reported.

series of ambiguous figures. For 3 of these they found the same version reported 'ambiguous' as did Fisher. For one of the stimuli used Fisher reports no data and for the remaining stimulus they found ambiguity judged to belong to a different version from Fisher.

In the initial selection procedure of the 15 versions, using the sophisticated Ss, Fisher notes that:

> "even when such relatively large number of alternatives are available, disagreement frequently arises over which figure should be included within the final selection. This necessitates introducing further modifications into them until agreement is reached." (p. 68, 1968b).

These modifications were made until the 15 versions were agreed upon.

Fisher here seems to be overlooking a most fascinating point. This is that he does not consider how the different versions actually do differ from one another. In the cases just described where disagreement existed and modifications were made to the drawings until agreement was reached he does not consider just what these particular modifications were. In initially drawing the different versions he himself must have an intuitive idea of what 'features' of the stimulus must progressively be changed from the one extreme version to the other. Casual inspection of any of his series of drawings indicates that he changes several things between two consecutive versions in a series. These include changes in length of lines, degree of closure of areas and texture. Figure 2.6 illustrates his 15 versions of Boring's figure.

The point made here is that what may primarily be important for the series of stimulus versions is a change in particular 'features' or particular parts of the picture. For the moment the word feature is used in an empirical sense to refer to parts of the stimulus figure such as specific areas of texture or a particular line in the stimulus. Disagreement between these Ss may have been resolved when some particular part of the stimulus was slightly altered. Furthermore, the series of such versions may reflect a gradual alteration in parts of the stimulus which are highly relevant for each particular aspect. Thus, emphasising specific parts, or features, relevent to one aspect while degrading those parts relevant to the other aspect will lead to more initial responses of the first aspect. In contrast, degrading the former parts and emphasising the latter will favour the second alternative aspect. What Fisher's work conceals is just what parts of the stimulus need to be so altered. It may be that only specific parts need to be altered, but by not knowing which are the relevant parts to start with, then simply altering a variety of different features

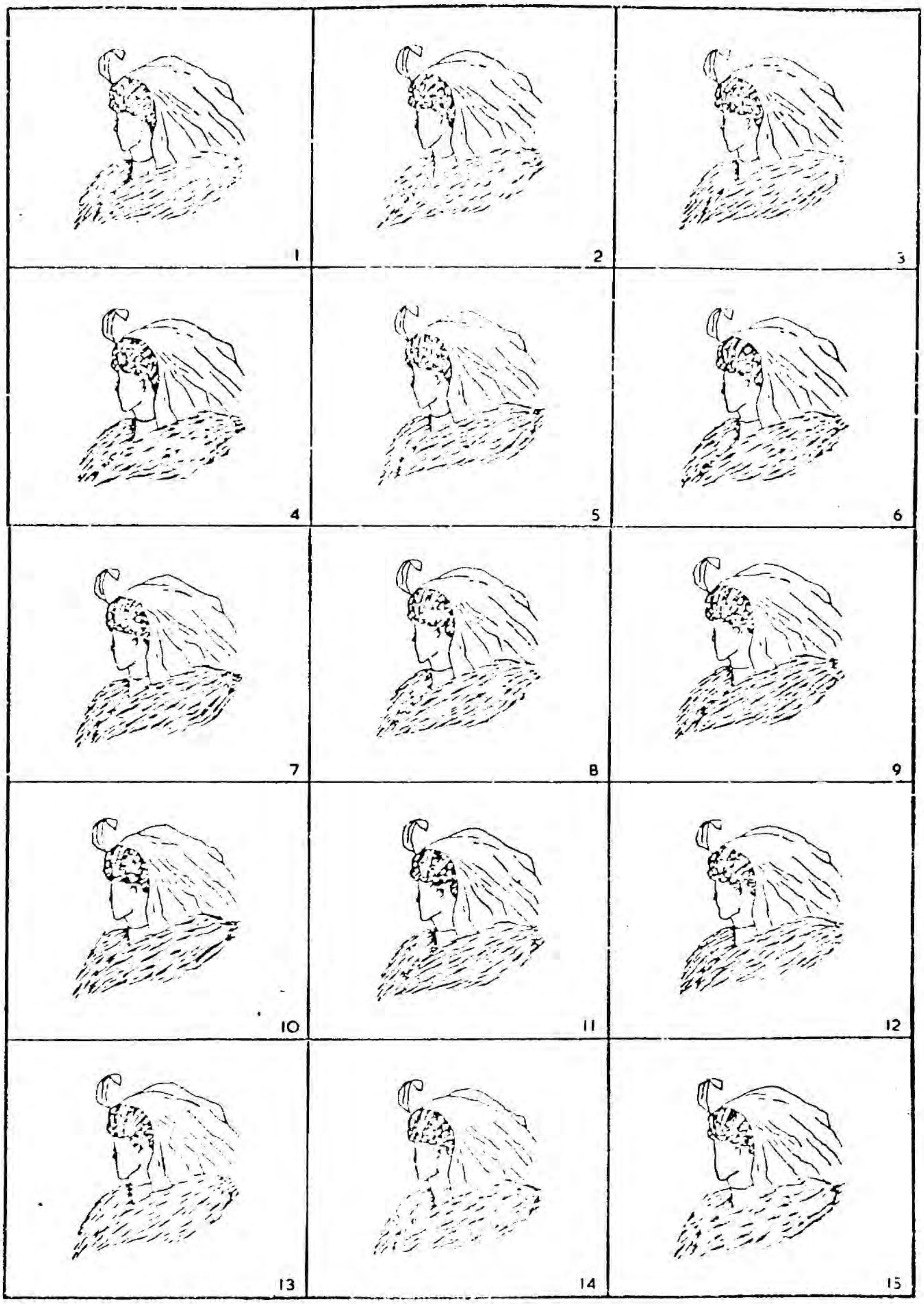


Figure 2.6 The 15 versions of Boring's ambiguous figure.

until agreement between Ss is reached, does not permit any determination of this.

Forsyth and Huber (1976) used 10 ambiguous figures representing 'human non-human' aspects, reporting that "minor physical alterations of each stimulus was made in order to achieve human responses from approximately 50% of a college freshman sample."

In Chastain and Burnham's (1975) work they initially determined 2 biased and one ambiguous version of the 'rat-man' figure by having an artist draw 9 versions of the figure so that "four increasingly emphasised man features, four increasingly emphasised rat features, and one was presumed neutral." Ss were then shown these being told that some would look more like a man and others more like a rat. Responses were on a numbered scale, limited to variations between these two interpretations. The final two unambiguous stimuli and ambiguous stimulus chosen were those closest to the 25th, 75th, and 50th percentiles respectively. Portions of these stimuli were then shown in subsequent experiments in a segmented fashion, the experimenters choosing two segments as representing unequivocal man and rat perception. This experiment has been discussed earlier in section 2.3.4. Chastain and Burnham present no evidence to support the implicit idea that the Ss' choice of such stimuli were due to such specific sector information. The differences between the three versions they show exist in several different places on the stimuli (Figure 2.1). Again the point is made that just what the main feature changes were between the 9 stimuli which affected the Ss responses in this manner is particularly interesting. It may be that specific changes in the sector areas designated by Chastain and Burnham for these two aspects are the 'prime' changes affecting the perception of these aspects but they present no evidence to support this. The need to systematically define the effect particular features or stimulus areas have upon the perception of that stimulus is important before altering several features to hopefully affect its subsequent perception.

2.8. STIMULUS ELEMENTS AND SELECTIVE ATTENTION

The question that can now be asked is whether specific parts of an ambiguous or reversible perspective stimulus can be identified as being important for the perception as figure of one or other aspect. The perception of figure in these stimuli may then be related to eye movements which serve to cause the S to selectively attend to such different areas. If it is possible to identify particular stimulus parts then altering (such as by removing or adding) these parts ought to produce a predictable effect upon the perception of the stimulus pattern.

The first clarification to be made is a definition of what is meant by 'specific parts' of a picture. The term 'feature' is often used in psychology, without being defined, to refer to some stimulus attribute. This term 'feature' seems applicable to stimulus attributes to which parts of the visual system are selectively sensitive (e.g. lines, angles). Such feature detectors in the visual system essentially reduce the redundancy present in the stimulus information (Barlow, Narasimhan and Rosenfeld, 1972). Sutherland (1973) has distinguished 3 classes of such features: local features (e.g. junctions of lines), global features (e.g. symmetry) and concatenations of local features. Neurophysiological work (e.g. Hubel and Wiesel, 1962, 1968) has demonstrated the existence of a variety of cells which selectively respond to particular stimulus attributes in an essentially serial and hierarchical fashion. For example, simple cortical cells can be regarded as line or edge detectors, complex cells as slant detectors (Cornsweet, 1970) and hypercomplex cells as detectors of such stimulus parameters as angles. Evidence also exists to demonstrate that besides such a serial fashion some parallel processing of stimulus attributes by independent analysers also occurs (Saraga and Shallice, 1973; Hawkins, 1969; Peeke and Stone,1973). Visual information is also encoded by channels which are selective to particular spatial frequencies (e.g. Cambell and Robson, 1968; Maffei and Fiorentini, 1973).

It is proposed here to use the term 'element' to refer to a line or collection of lines in a picture which may be a collection of individual features but which together represent an identifiable attribute of the object represented by that stimulus. Thus, in a line drawing of a face an 'eye' will essentially be composed of several lines, angles, etc., but these separate features together constitute an element (an 'eye') which is recognised. This definition comes close to that used by Kennedy (1974) in describing pictures and is similar to the 'distinctive features' of real objects (Hagen, 1974). With a stimulus such as a Necker cube then an element will be a line, an angle or an area - in this case the term in equivalent to the same term used by Vitz and Todd (1971) for describing simple geometric figures.

The following working hypothesis is thus proposed: any figure generally depicting two alternative possible aspects will be composed of stimulus elements, some of which will more represent one aspect than the other and some which will represent both aspects to some lesser extent. What is envisaged is that across the stimulus a probability distribution of elements favouring aspect A can be constructed as can a similar distribution for elements favouring aspect B. In these distributions, some stimulus elements will be important for each aspect (i.e. specific stimulus areas will have a high probability of being perceived as one particular aspect) and other parts will be either equivocal or less important (i.e. altering these lesser important elements will have little detrimental effect on the perception of the figure). These distributions will co-exist over the stimulus. The response of which aspect is perceived as figure will thus be a function of the distributions to which the observer selectively attends (e.g. by eye movements).

Models of selective attention have been proposed by Broadbent (1958, 1971) and Treisman (1969) amongst others. These models stress both the limited capacity of the system and the selective gating processes inherent in attention, e.g. Broadbent's 'filter' or Treisman's 'attenuation' concept. Part of the attention process is the selection of the appropriate stimulus analysers Treisman and Riley, 1969). Lindsay and Norman (1972) have proposed that attention mainly consists of a comparison between expectations and the product of these feature analysers.

Three different attentional fields have been characterised by Sanders (1970). The 'display field' is the area covered in a single glance (some 30^0) which is extended by saccadic eye movements up to about 80^o (the 'eye field'). Head movements then further extend this range to the 'head field.' Neisser (1967) has proposed that pre-attentive processes first segregate the stimulus in a global manner so that focal attention can occur to the figure which allows its features to be analysed. This process is essentially extra-foveal (Hochberg, 1970a) and occurs within the display field (Forgus and Melamed, 1976). Lockhead (1972) somewhat similarly has suggested that a stimulus is first processed as a whole or a 'blob' followed, if the task demands it, by serial processing of the stimulus attributes. Treisman, Sykes and Gelade (1977) have also pointed out the importance of selectively attending to particular spatial locations in a serial fashion.

The main instrument of such selective attention is eye movements. The importance of Hochberg's (1970a) approach is that it emphasises the way in which such movements are determined by the schematic map. Thus, on first exposure to a stimulus the pre-attentive processes will essentially segregate out a figure in terms of global features followed by an active synthesis of the 'attended-to' information.

The schematic map then guides the eye movements as these expectancies are tested and compared to the products of the detailed foveal analyses (c.f. Lindsay and Norman, 1972). The result of this process is the actual percept of figure. Thus, if a stimulus can give rise to different interpretations as figure then the response will be largely determined by which elements of the stimulus the S can selectively attend to and the bias or weighting of such elements towards one or other aspect. This selective attention will be 'manifested' as eye movements in situations where these are possible, whereas, in other situations (e.g. internally generated images) such selective attention may not be determined by eye movements.

2.9. A BRIEF EXPERIMENTAL GUIDE

The position taken in this thesis is that ambiguous and reversible perspective figures are composed of elements, some of which are relevant to both of the major possible aspects. Other elements are considered as having a higher probability of being interpreted as one of the aspects. Thus for any such stimulus it ought to be possible to map out these distributions. The initial appearance of these stimuli will depend both upon the past experience and also upon the initial locus of fixation. This initial fixation location will help to determine the schematic map subsequently tested (c.f. Chastain and Burnham, 1975). Other fixations will then be made with an appropriate expectancy. Given that such areas of the picture can be identified then the interesting question can be asked of what happens when a perceptual fluctuation occurs?

Hochberg argues that perceptual idling is the main cause of fluctuation when fixations are made with no definite expectation and if an area is then fixated which fits the alternate schematic map then this particular test programme is undertaken with other stimulus areas now being fixated with this latter expectancy. Does the subject then need to fixate an area highly favouring the alternate aspect before such a reversal occurs or does he fixate such an area after such a reversal, in order to confirm his expectation? A third alternative is that fluctuation and change in fixation location occur together. All three may well happen, but without first defining which areas of the stimulus are 'biased' elements then there is no way to determine any possible causal relationships between eye movement patterns, fluctuations, stimulus pattern elements, and the perception of figure.

Previous research investigating the role of eye movements in the perception of ambiguous or reversible perspective figures has either used a large stimulus, with recording of the S's eye movements, but in conditions in which the S was very aware that this was the case. Alternatively, in stabilised image conditions a relatively small stimulus size has tended to be used. Fluctuations in such instances possibly being related to the ability to shift attention around the stabilised image (e.g. Pritchard, 1958). The stabilised image condition is, however, a useful approach as it permits focal attention to be determined to certain elements whilst other stimulus parts are viewed extra-foveally. This is particularly the case for a large stimulus. This is in contrast to partial presentation methods where only specific areas are viewed. In this sense the stabilised condition can more nearly approximate a fixation made at this position in normal non-stabilised viewing. This is not to say it is directly equivalent to such normal viewing only that the stimulus information to the S is similar.

From the foregoing discussion of the effects of prior experience and variations in stimulus appearance it would seem that the choice of an ambiguous figure rather than a reversible perspective one may more readily demonstrate the existence of such weighted elements. This is not to suggest that an effect found in the case of an ambiguous figure will not function similarly for reversible perspective figures. Only that the former are a more suitable stimulus for this work. Reversible perspective figures can depict many possible aspects besides any experimentally determined two alternate aspects thus possibly complicating any study of the distribution of two schematic maps.

The following experimental hypotheses are proposed from the foregoing discussion. These are then elaborated and examined in the subsequent chapters.

It is hypothesised that ambiguous and reversible perspective figures can be considered as being composed of identifiable elements. Some of these elements are strongly biased or weighted toward one or other particular aspect. Other elements are not so differentially weighted towards either aspect. The response of figure to such a stimulus is hypothesised to be a function of the element or elements to which the observer can selectively attend. The use of a large ambiguous figure in a stabilised viewing situation is suggested to provide a good situation in which to examine these proposals. These hypotheses are tested in Experiment 1 after the selection of both a suitable ambiguous figure and an appropriate stabilised image technique.

Given that the distribution of the aspect weightings can be elaborated then it is hypothesised that altering (by removing or adding) particular weighted elements of the stimulus when it is viewed as a stabilised image should affect the response of figure obtained. That is, when the weighted elements available to the S at a given fixation position are altered then if the response of figure is determined by the presence of these elements then their absence should alter the response to that of the alternate aspect. Experiments 2 and 3 test this.

The above results ought not to apply solely to stabilised image situations where the observer's fixation location is determined by the experimenter. It is hypothesised that having determined the effectiveness of particular elements in a stabilised condition then presenting similarly altered variations of the stimulus in a free viewing situation ought to have predictable results upon the interpretation of the stimulus. Experiment 4 examines this.

Schematic maps are available for the 'mature' observer (Hochberg, 1970a). Thus, it is hypothesised that children may not have such adequate schematic maps for these variations of the ambiguous figure and so age related differences in the response to such freely viewed versions should be found. These differences are proposed to reflect the ability to integrate the weighted elements into the appropriate map. Younger children are proposed not to be able to integrate as well as older children. Thus, whereas the performance of older children should approximate that of the subjects in the previous experiment, altering the weighted elements should have a poorer effect for the younger children. This is studied in Experiment 5.

Having determined the distribution of aspect weightings then when eye movements are secretly recorded whilst a S freely views the ambiguous stimulus his fixation locations are hypothesised to concur with those elements found important for each aspect. What happens when the stimulus fluctuates can then be studied. It is hypothesised that the observer's fixation locations will shift from one stimulus area, favouring one aspect, to another, favouring the alternate aspect, as fluctuations occur. Experiment 6 reports this work.

The stabilised image experiments are presented in Chapter 3 followed in Chapter 4 by the two free viewing experiments. The design and construction of suitable equipment to record the observer's eye movements is detailed in Chapter 5. Eye movement recordings whilst observers viewed the ambiguous figure and its variations are presented in Chapter 6.

2.10. SUMMARY

The various parameters which affect the perception of figure in reversible and ambiguous figures have been considered. It is proposed that the role of eye movements in the perception of such stimuli has not been adequately examined. Attempts to generate alternate versions of ambiguous figures are suggested to demonstrate the existence of possible stimulus elements weighted towards one or other aspect. The perception of figure is then a function of the weighted elements available to an observer at a given fixation location. Eye movements serve to shift the centre of the observer's attention about the stimulus display and so the response of figure is hypothesised to alter as different weighted elements become more available. It is proposed that Hochberg's theory (c.f. Chapter 1) offers an explanation for how eye movements are related to the perception of such stimuli. Finally experimental hypotheses are generated which are examined in later chapters.

CHAPTER 3

THE AFTERIMAGE STUDIES

3.1. INTRODUCTION

The previous chapters have led to the hypothesis that a stimulus which can give rise to more than the one figure can be considered as being composed of elements. The perception of a particular aspect as figure is proposed to be a result of a combination of both fixation location and the contribution of these elements of the stimulus.

In this chapter this hypothesis is investigated. Firstly the ambiguous figure used in this and the subsequent chapters to test this hypothesis is described and the several representations of it by different authors are illustrated. Next a method is elaborated which would allow presentation of the ambiguous figure to a S in such a way that his fixation position upon the figure could be controlled. This was achieved by using a stabilised image technique. A pilot study was carried out to determine the best way of presenting the stimulus by this method. This resulted in a simplified line drawing of the ambiguous figure which it is argued contains four important elements relevant to the perception of both aspects.

By the use of different fixation positions across the stimulus the role of both fixation position and picture elements are examined in the first experiment.

The second and third experiments use the same stabilised technique. The second experiment investigated the effect of the presence or absence of two of the elements using two different fixation positions. The third experiment extended this study to all four of the elements. In addition, the second experiment examined the influence of altering the fixation position upon which aspect of a Necker cube stimulus was reported as figure.

3.2. BORING'S AMBIGUOUS FIGURE

The choice of stimulus figure for the proposed research was Boring's (1930) ambiguous figure. This was selected for several reasons. Firstly, an ambiguous figure was preferred to a reversible perspective figure for considerations stated previously in Chapter 2. Secondly, some authors (e.g. Gregory, 1970 ; Hochberg, 1970a) have already remarked that one aspect of the figure is favoured by looking at certain regions. Hochberg specifically suggested, without citing any experimental evidence, that looking in a particular area encompassing the nose of the young woman favours this aspect, whereas a second area in the picture, encompassing the mouth of the old woman, favours this alternate aspect (Figure 3.2(b)).

Figure 3.1 The original ambiguous figure drawn by Hill(1915)

Thirdly, this is singularly the most popularly presented example of an ambiguous figure and therefore it seemed most appropriate to investigate the existence of the aforementioned 'pictorial elements' in this figure.

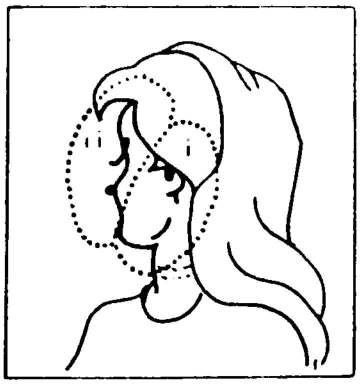
Originally published by Hill (1915) under the title "my wife and my mother-in-law" the ambiguous figure (shown in Figure 3. 1)was popularised by Boring (1930). Boring stated that it depicted:

> "...the left profile of a young woman, three-quarters from behind. The other figure is an old woman, three-quarters from in front. The ear of the 'wife' is the left eye of the 'mother-in-law' the left eye-lash of the former is the right eye-lash of the latter; the jaw of the former is the nose of the latter; the neck ribbon of the former, the mouth of the latter." (p.445)

Boring's drawing of the figure is shown in Figure 3.2 (a). Subsequently, this ambiguous figure has appeared in various textbooks of psychology and scientific papers. Typically it is shown in a left facing direction, Neisser (1967) alone presenting a right facing version (Figure 3.3 (b)).

Gregory has presented a slightly different version to Boring in that the chin of the old woman is cut off by the base of the picture and the treatment of the young woman's nose is less emphasised (Figure 3.2 (c)). Haber and Hershenson (1973) have illustrated a version closely similar to that of Boring, but without Boring's textured

(a) Boring (1930)



(b) Hochberg (1970a)

(c) Gregory (1970)

(d) Haber & Hershenson (1973)

(e) Fisher(1967a)

Figure 3.2 Representations of the ambiguous figure shading of hair and coat (Figure 3.2(d)). Attneave (1971) uses Boring's original drawing, whereas, Fisher (1967a) has arrived at yet another ambiguous version of the figure (Figure 3.2(e)). Julesz (1974) uses Gregory's representation while Hochberg (1970a)has presented only a very rough drawing (Figure 3.2(b)).

Additional versions of the figure have been drawn to represent either the young woman or the old woman aspects. Leeper (1935) constructed three versions of the figure, 2 biased towards either aspect, and one being ambiguous. These are shown in Figure 3.3(a). Leeper's ambiguous version was a "somewhat rough copy" of Boring's original. Leeper commented that there were "quite a few differences between the single-phase drawing of the young woman and the picture of the young woman in the composite." In Leeper's old woman version the nose of the young woman is omitted and the left eye of the old woman emphasised. Otherwise the figure is rather similar to the ambiguous version. For the young woman version, however, several major alterations are made, e.g. the neck is elongated with the mouth of the old woman lengthened into a necklace, the nose of the young woman is emphasised. The major difference with the young woman version is in the treatment of the head outline which is completely altered, being much smaller. Leeper's versions do not include the feather which was present in Boring's drawing.

In Neisser's representation of Leeper's versions the head sizes are kept the same (Figure 3.3(b)). The old woman lacks the feather present in the ambiguous version and the mouth and nose of the old woman are elaborated with the removal of the young woman's nose. In the young woman version this last aspect is emphasised as is the feather with the mouth of the old woman, or necklace of the young woman, barely present.

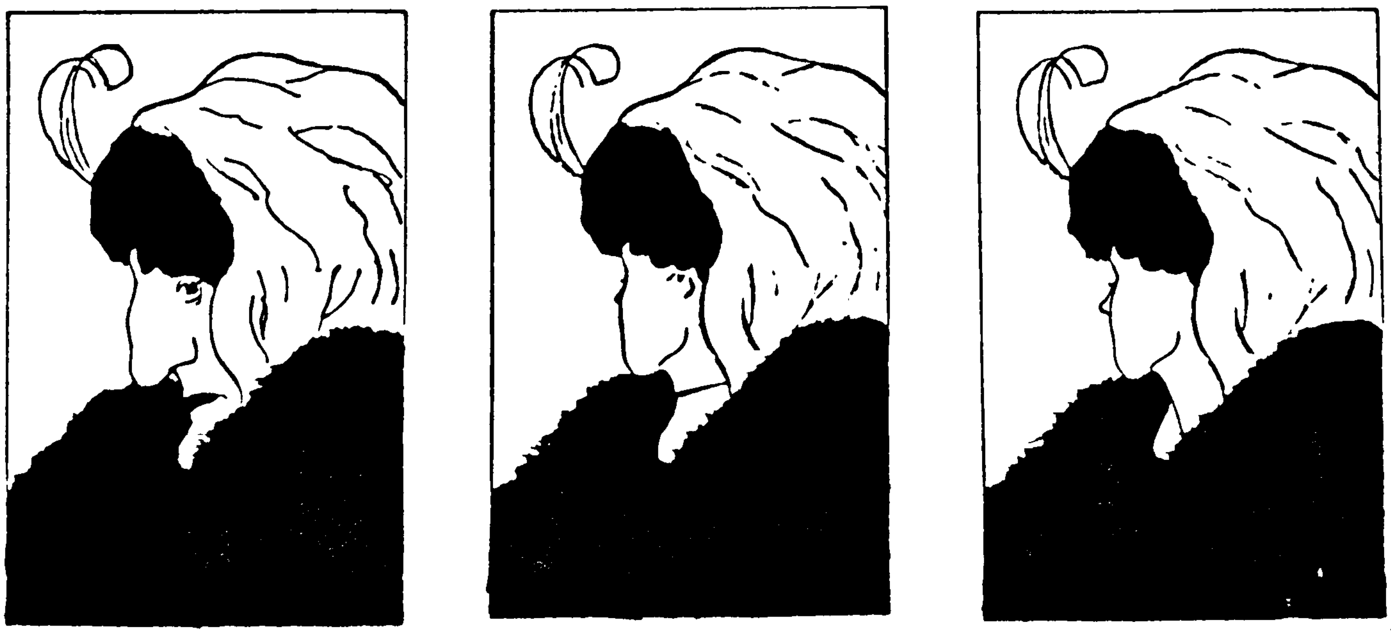
Similarly Fisher emphasises, in his young woman version, the nose of the young woman with the ear being more 'ear-like' and less like an eye, also the necklace is represented as a uniform band. In the old woman version the eye is emphasised, the young woman's nose is absent and the mouth of the old woman is an irregular band (Figure 3.2(c). Figure 3.2(d) is due to Rock (1975).

In constructing these different versions each author emphasises different features. Although there seems agreement upon emphasis of the young woman's nose for the young woman biased version, together with an alteration in the eye/ear and mouth elements. For the old woman aspect the young woman's nose is omitted or degraded and the eye/ear emphasised as an eye. The nose and mouth of the old woman are also exaggerated.

(a) Leeper (1935)

(b) Neisser (1967)

(c) Fisher (1967a)



(d) Rock (1975)

Old Woman Version	Ambiguous Version	Young Woman Version

Figure 3.3 Different representations of the ambiguous and unambiguous versions of Boring's figure.

These alterations are also accompanied by changes made elsewhere in the picture. No one has studied whether all of these changes are necessary or just what change to which element of the picture is possibly sufficient by itself to reliably affect perception of the picture.

Boring (1930) originally considered this ambiguous figure to be "the best of the puzzle-pictures in the sense that neither figure is favoured over the other." Subsequent research has shown this not to be the case. In Leeper's study (1935) 65% of the control group which was given no preliminary preparation reported the young woman aspect on first observation of the drawing, whereas 35% reported the old woman. Botwinick, Robbin and Brinley (1959) found that the young woman aspect was predominantly reported. Likewise, Ramamurthi and Parameswaran (1964) found a preponderance of young woman reports. Carlson (1953) used three versions of the ambiguous figure and found that, whereas the young woman version was only seen as young woman, the old woman version merely 'favoured' this aspect over that of the young woman. There was a general preference to see the young woman in the ambiguous version. Lindauer (1969) found in contrast, with a series of eight versions of Boring's figure, that in general there was a preponderance of the old woman response across these stimuli

The existence of the different drawings of Boring's ambiguous figure together with reports of a general preference to perceive the young woman aspect in it support the argument that this stimulus is an ideal choice to examine the hypothesised role played by particular 'picture elements'. The bias to perceive the one aspect may well be related to the way in which the ambiguous figure has been drawn.

3.3. STABILISED IMAGE TECHNIQUES

A method of presenting Boring's ambiguous figure so that its image would be stabilised upon the retina was required. This could be accomplished by several techniques: an optical lever system, directly attaching the stimulus to the eye, imaging internal structures of the eye upon the retina, immobilising the eye, or by exposing the stimulus to a bright flash of light. These different methods are briefly considered and then the most appropriate is selected.

Optical Lever System. This technique uses a mirror attached to a contact lens fitted over the eye. An optical system projects the stimulus target onto this mirror in such a way that when the eye moves so too does the contact lens and mirror. This stimulus is then stabilised as long as the contact lens does not slip. The S either views the image from a screen or else the image is directly focussed upon the pupil (Heckenmueller, 1968). Ratliff and Riggs (1950) described such a system which compensated for eye movements and for their magnitude by altering the projected optical path of the target. Because the mirror was directly mounted on the contact lens only horizontal eye movements could be accounted for. Clowes and Ditchburn (1959) compensated for both vertical and horizontal movements by mounting the mirror on a small stalk attached to the contact lens. Both approaches require accurate stabilisation of the S's head.

Direct Attachment of the Stimulus. Targets have been fastened directly to the contact lens on the S's eye (Ditchburn and Pritchard, 1956). By mounting the target on a stalk and illuminating it with collimated light (the collimator also was attached to the stalk) then the image appeared at optical infinity.

Internal Eye Structures. Internal structures of the eye, such as shadows of retinal capillaries or macular pigment appearance (Campbell and Robson, 1961), can be imaged on the retina. Other entopic phenomena such as 'Haidinger's brushes' (Ratliff 1958), which have an hour glass shape, can be utilised.

They are best observed by monocularly viewing a bright field of blue light through a polariser rotating at 1 Hz (Coren, 1971; Coren and Kaplan, 1972).

Eye Immobilisation. The eye can be immobilised through paralysing the extraocular muscles (Kornmüller, 1930) with a suitable drug such as Curare (Zinchenko and Vergiles, 1972).

Afterimages. A flash of light produces similar stabilisation (Bennett-Clark and Evans, 1963) of the retinal image by means of the afterimage so created. Targets on a transparent background attached to a rear light source can be used or else high contrast stimuli can be briefly illuminated (Evans, 1966).

Review and Choice of Technique

Systems using contact lenses are subject to slippage with respect to the eye (Barlow, 1963) as well as being unpopular with Ss and expensive. Eye immobilisation through drug injections is not practical for a large number of Ss. Entopic phenomena are useful but the ease and simplicity of afterimages renders the last approach the one chosen here. It is also the one most amenable to the use of large stimuli.

Fragmentation. The main problem with a stabilised image approach is fragmentation of the image. Several workers have studied stabilised image phenomena using the above techniques demonstrating that relatively similar effects are produced by the different methods (e.g. Evans, 1966; Heckenmueller, 1968). In general a stimulus viewed in such a fashion will disappear and reappear, i.e. fragment, either as a whole or in parts. This is not due to factors such as slippage of a contact lens (Fiorentini and Ercoles, 1963).

Fragmentation appears to be affected by several factors. Meaningful stimuli remain visible longer than meaningless stimuli (Arnold, Meudell and Pease, 1968; Wade, 1974). Parts of the stimulus being attended to likewise remaining visible longer (Heckenmueller, 1968). Jagged stimuli appear to be less stable and fragment more easily than rounded ones (Pritchard, Heron and Hebb, 1960). Acute and obtuse angles disappear more than right angles (McFarland, 1968) and are affected by the orientation of the angle (Schmidt, Fulgham, and Brown, 1971). Straight lines tend to act as units and fragment as a whole. In a complex stimulus parts of it fragment in apparently 'good', in the Gestalt sense, organisations (Pritchard, Heron and Hebb,1960; MacKinnon, 1971). Perceptual closure has also been reported to occur with fragmentation (Pritchard, Heron and Hebb, 1960; Gregory and Arnold, 1971). Wade (1978) has recently reviewed the fragmentation and fluctuation effects in afterimages.

Most of this work has usually been directed to the investigation of other issues rather than the present interest in the perception of a stabilised image of an ambiguous stimulus. The importance of fragmentation in the latter instance is that if a S is reporting his perception of a stabilised image which is fragmenting, this very process may produce different cues to each aspect so affecting the S's response

3.4. THE PILOT STUDY

3.4.1. Introduction

Having decided upon the ambiguous figure to be used and the technique of stabilising the retinal image of this stimulus consideration was then given to the need for the ambiguous figure to give rise to an adequate afterimage. The appearance of the afterimage produced had to be able to be reported as either the young or old woman. This would be complicated if the afterimage rapidly fragmented as the fragmentation may selectively aid the perception of one or other aspect. An experimental arrangement was thus required which would produce an afterimage, the appearance of which could be reported before such fragmentation occurred.

Boring's ambiguous figure was first redrawn as a line drawing in order to facilitate the perception of the ambiguous figure in conditions of stabilised image presentation as well as to remove any confounding effects of texture cues. A pilot study was then carried out, firstly to determine whether this line drawing version of the ambiguous figure could represent both of the possible aspects and further to determine the parameters of such a stimulus. The stimulus parameters investigated included the following. The stimulus size had to be such that Ss could perceive both aspects in the stimulus and yet permit foveal vision to be determined to only specific parts of the stimulus. A suitable technique for controlling fixation position to achieve this had to be devised. The appropriate line width of the stimulus as well as whether the best afterimage was painted using either a white line drawing on a black background or vice versa.

The pilot study was carried out in two parts. In the first, different stimuli were used and in the second different instructions and viewing distances were employed.

3.4.2. Part 1.

Subjects. Eight undergraduate Ss (five males and three females) took part.

Apparatus. Boring's ambiguous figure (1930) was reproduced as an outline drawing of various sizes by using a pantograph to enlarge the original. Both black line drawings on white backgrounds as well as white drawings on black backgrounds were constructed. The white line drawings on a black background were formed by using cut-out white card on a black card ground. The black line drawings on a white background were produced both in a similar fashion (using black cut-out card on a white card background) and also by using black Indian ink to draw the outline figure. Luminous fixation spots were made by using truncated pin heads covered in luminous paint.

A Metz Meccablitz 502 flashgun served as the light source to produce the afterimages. This was placed on a table between the S's position and the target stimulus position and directed at the stimulus.

For some Ss a stopwatch was used to time the sequence of the reported appearance of the experienced afterimage.

Procedure. Ss were seated at the table in a darkened room with the flashgun in front of them and allowed to dark adapt for several minutes, their non-preferred eye having been occluded by an eyepatch. One of the stimulus cards was then introduced at the other end of the table with the luminous fixation spot positioned upon it. Ss were instructed to fixate the spot and then discharge the flashgun in front of them whereupon they were to lightly close both of their eyes and then verbally report what they saw.

3.4.3. Part 2.

Subjects. Twenty Ss (twelve males and eight females), all undergraduates were used.

Apparatus. As for Part 1.

Procedure. The general procedure was as in Part 1. Various pre-experimental instructions were given and the Ss were seated at different distances from the stimulus. For some presentations parts of the stimulus were occluded by white paper (where the stimulus was a black line drawing on a white ground) or black paper (for white on black ground stimuli). This meant that the occluded part was then not present in the S's afterimage.

3.4.4. General Results and Discussion

The following was the sequence of afterimage appearance typically reported by Ss when the black line drawing stimulus was used. On discharge of the flashgun a short duration flash ensued followed by a period of some seconds (5-7 s) during which no figure was visible. The white square then appeared, often being purple-white in colour. This was followed by the extremely rapid building up of the constituent lines of the figure until the complete positive afterimage was visible for a few seconds during which time Ss reported what the stimulus represented. The figure then gradually fragmented eventually resulting in the negative afterimage of the stimulus which again tnen fragmented until complete disappearance of the afterimage was reported about one minute or so after the initial flash.

White figures on a black background produced afterimages which were unclear and fragmented quickly and which were poorly reported. Black stimuli on white backgrounds producing apparently 'clearer' afterimages (i.e. Ss were able to describe their perception better). Those stimuli which were constructed from cut-out black card were more susceptible to faster fragmentation than were the black line drawings. The former stimuli were also more 'jagged' in appearance compared to the more rounded ink-drawn versions.

A black Indian ink drawing on a white background, size 40 cms x 30.5 cms with a line thickness of 0.64 cms, produced the best afterimages at a distance of 61 cms from the S. At this distance this size of stimulus met the criterion of affording differential foveal vision to be paid to certain parts of the stimulus while other stimulus areas were viewed more peripherally. A centrally located fixation position on the stimulus card (positioned near the element representing the ear of the young woman or the eye of the old woman) allowed Ss who had previously been shown a photograph of Boring's figure to alternate their responses between the two aspects in the afterimage. On questioning afterwards all the Ss considered the line drawing to be a good representation of the original figure.

Completely naive observers when asked to report their perceptions sometimes reported changing colours in the afterimage. Naive Ss were also often biased with respect to which aspect they reported. The young woman being reported more often.

The flashgun discharge besides illuminating the stimulus also increased the luminosity of the luminous fixation spot. Having Ss close their eyes lightly after the discharge prevented the possible subsequent perception of this spot undergoing apparent autokinesis which might detract from reporting the afterimage appearance. This procedure is commonly used in afterimage studies (e.g. Wade, 1974). The other possible effect of the discharge upon the fixation spot was that if the fixation spot was located directly on one of the lines of the drawing then this may affect the appearance of that line in the afterimage. For this reason the fixation spots were always placed near particular lines rather than on them.

When Ss were previously familiarised with both aspects of the ambiguous figure then varying the fixation spot position and occluding various stimulus parts resulted in the following:

A fixation position near the young woman's nose produced solely young woman responses; fixation near the ear/eye produced responses of both aspects, whereas fixation near the mouth of the old woman produced more responses of this latter aspect.

When the nose of the young woman was occluded and fixation was near this then more old woman responses were elicited. This was in contrast to the finding when this feature was present. When the lines constituting the old woman's mouth were partially occluded this appeared to have little effect.

Presence or absence of the 'feather' in the ambiguous figure did not produce a difference in response to any fixation position. From the Ss' descriptions after the experiment it was deemed that this item served mainly to confuse the response of 'old-fashioned in appearance' of both aspects.

3.4.5. Summary

The pilot study showed that an afterimage of a line drawing of Boring's ambiguous figure could give rise to both young woman and old woman responses. A suitable size of stimulus was determined and the use of luminous fixation spots permitted control of fixation position prior to painting the afterimage. It also demonstrated the need for Ss to be made aware of the two aspects in the stimulus and to be familiarised with the general appearance of such afterimages.

3.5. THE LINE DRAWING OF BORING'S AMBIGUOUS FIGURE

The resultant line drawing of the ambiguous figure is shown in Figure 3.4 . It can be considered as being constructed from a series of lines which together constitute an overall 'facial' area together with other lines which it is proposed can be construed as four elements. These four elements are:-

a) YE. The young woman's eyelash and nose, or the old woman's second eye.

b) E/EC. The ear of the young woman or eye of the old woman.

c) CL. The cheekline of the young woman or part of the nose of

Figure 3.4 The line drawing and the 4 elements.

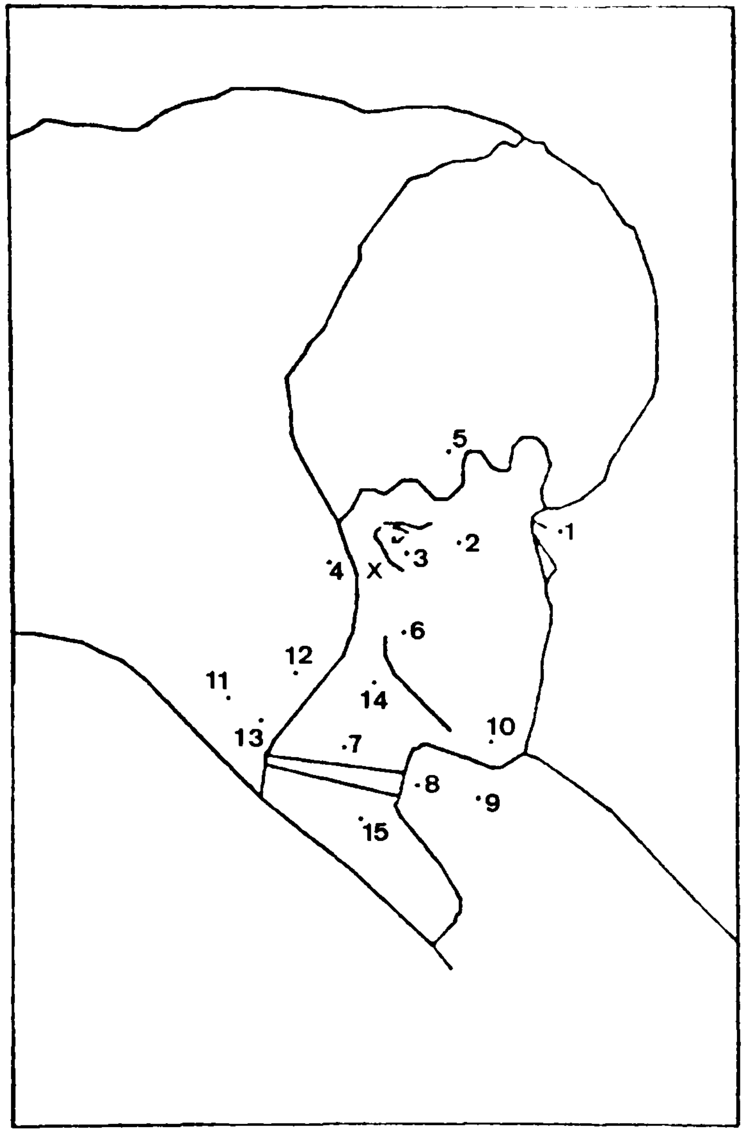


Figure 3.5 The 15 fixation positions and the central fixation point(x).

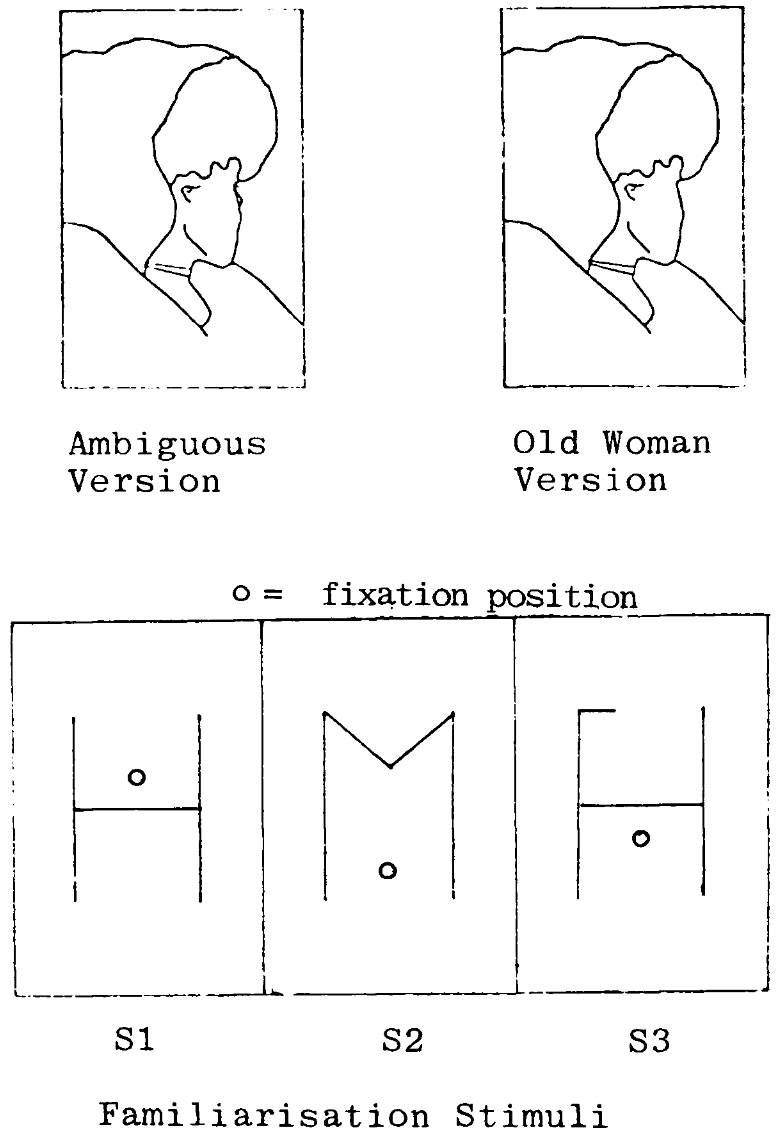


Figure 3.6 The 2 versions of Boring's figure and familiarisation stimuli.

the old woman aspect.

d) M. The necklace of the young woman or mouth of the old woman.

The lines considered as constituting each element are also shown in the same Figure.

The two possible responses to this stimulus are as young woman or as old woman. These are characterised as YW and OW respectively.

3.6. EXPERIMENT 1.

3.6.1. Introduction

The pilot study determined the best size of stimulus to use so that Ss could report both aspects yet by altering the fixation position, before painting the afterimage of the stimulus, visual attention could be controlled to specific stimulus areas. The purpose of the first experiment was to test the hypothesis that fixation in different areas of the stimulus would produce different proportions of young or old woman responses. The perception of an aspect being largely dependent upon what elements are within focal vision at a particular fixation position.

Using an afterimage technique Ss were required to respond which aspect the positive afterimage represented. Some practice with reporting the appearance of afterimages of other stimuli was first necessary to ensure familiarity with the general appearance of such images to avoid irrelevant responses (e.g. colour changes). Ss were also familiarised with the ambiguous figure itself to ensure the availability of a response representing each aspect. This was to overcome any possible stereotype to respond to only the one aspect.

For these two reasons a technique of afterimage familiarisation and practice with alternating the response to the ambiguous stimulus was employed before studying the effect of altering fixation position.

From the pilot study results, together with the consideration of how other authors have drawn the ambiguous figure in biased fashions, it was hypothesised that fixation near the YE element would produce more YW responses and fixation near the M element more OW responses.

A possible, although simplistic, explanation for the perception of the overall figure could be proposed such that the YW aspect was mainly a result of fixation near the YE element, the OW aspect could be due to the similar effect of a single element (M) with the other two elements and overall facial lines tending to represent both aspects. Thus, for a fixation position near the E/EC or CL elements no dominant response of YW or OW would be predicted. To test such a proposed distribution of responses across the figure 15 fixation positions were chosen, these being selected from those used in the pilot study. These positions were located both near specific elements and also elsewhere on the stimulus.

Boring's ambiguous figure is almost exclusively presented in a left-facing fashion. Both left and right facing versions were used here to see if any difference in response was obtained. For instance, if the YE element did strongly elicit YW responses then in a left facing version this may, on the basis of left to right reading eye movement habits, be the first element commonly encountered. This may then be related to the usual finding that this ambiguous figure is perceived as more often representing the young woman aspect.

To check that a response of YW when fixation was near the YE element was actually due to the presence of this element and not just due to fixation in that general part of the picture an additional stimulus condition was incorporated where the stimulus did not contain this element. Thus, the S's responses could be compared for the same fixation position but with this element present or absent. It was hypothesised that omitting this element would produce more OW responses than when it was present, thus demonstrating that the response was largely due to this element particularly representing the one aspect as compared to fixation position alone.

3.6.2. Subjects

Twenty first year psychology undergraduates (10 males and 10 females) served as Ss.

3.6.3. Stimuli

Following the determination of the stimulus given in the pilot study the following four stimuli were constructed by the same means. All stimuli were drawn in black Indian ink with a line thickness of 0.64 cms on a white card background of size 40 cms high x 30.5 cms wide. Total size of the card was 40 x 40 cms, the extra width being on the left hand side and covered in black fablon for handling purposes.

Two of the cards were a left facing (AL) and right facing (AR) line drawing of Boring's original figure. The other two cards were drawn in similar fashion but without the YE element, one card facing right (OR) and the other left (OL).

All four stimuli had 15 pinholes in identical positions with respect to the stimulus figure as shown in Figure 3. 5 . A truncated pinhead covered in luminous paint served as the fixation spot. The fixation position was altered by siting the pinhead in one of the pinholes prior to discharge of the flashgun.

An additional stimulus card, the same overall size, served to provide three different stimuli to familiarise Ss with afterimage appearance. These stimuli were S_1, S_2, and S_3. The line drawing was 22.5 cms high by 16.5 cms wide. To produce the three stimuli, parts of the line drawing were occluded by white card in conjunction with a particular fixation position prior to presenting it to the S. These three stimuli and their relevant fixation positions together with the drawings of Boring's figures used are shown in Figure 3. 6 .

3.6.4. Apparatus

The apparatus is shown in Figure 3. 7 and Figure 3. 8 . A black stimulus card holder was positioned at one end of a light proof 'box' consisting of a wooden framework supporting a black sugar paper interior. The end of the 'box' opposite the stimulus was open. In this opening was positioned a combined head and adjustable chin-rest. The viewing distance was 61 cms.

The flash head of the flashgun (Metz Meccablitz 502) was mounted directly in front of the chin rest just below eye level. The flash duration was .001s and its energy was 120 $W.s^{-1}$

One side of the box was removable to allow stimuli to be mounted on the holder and for positioning the fixation spot on the stimulus. A small light bulb (40W) was placed in front of the stimulus holder at the base of the box. Between the S's position and the stimulus were two matt black masks to limit the S's field of view to the stimulus, with the lower one also occluding the light bulb. A matt black card (card B) could be slid horizontally across the box just behind the masks so making a light proof area between it and the stimulus holder.

The flashgun was fitted with a remote discharge button operated by S. The charging unit of the flashgun was outside the box. The experimenter (E) sat at the side of the box with a stopwatch. A small darkroom light was used so as to be able to record responses, whilst maintaining the room in relative darkness.

3.6.5. Procedure

The S's eye preference was first determined by asking which eye was used for sighting a rifle or viewing through a telescope. The non-preferred eye was then occluded by an eye patch.

The S was then seated with his chin on the chin rest and its height adjusted until the S's preferred eye was at the same height as the centre of the stimulus card holder and thus vertically

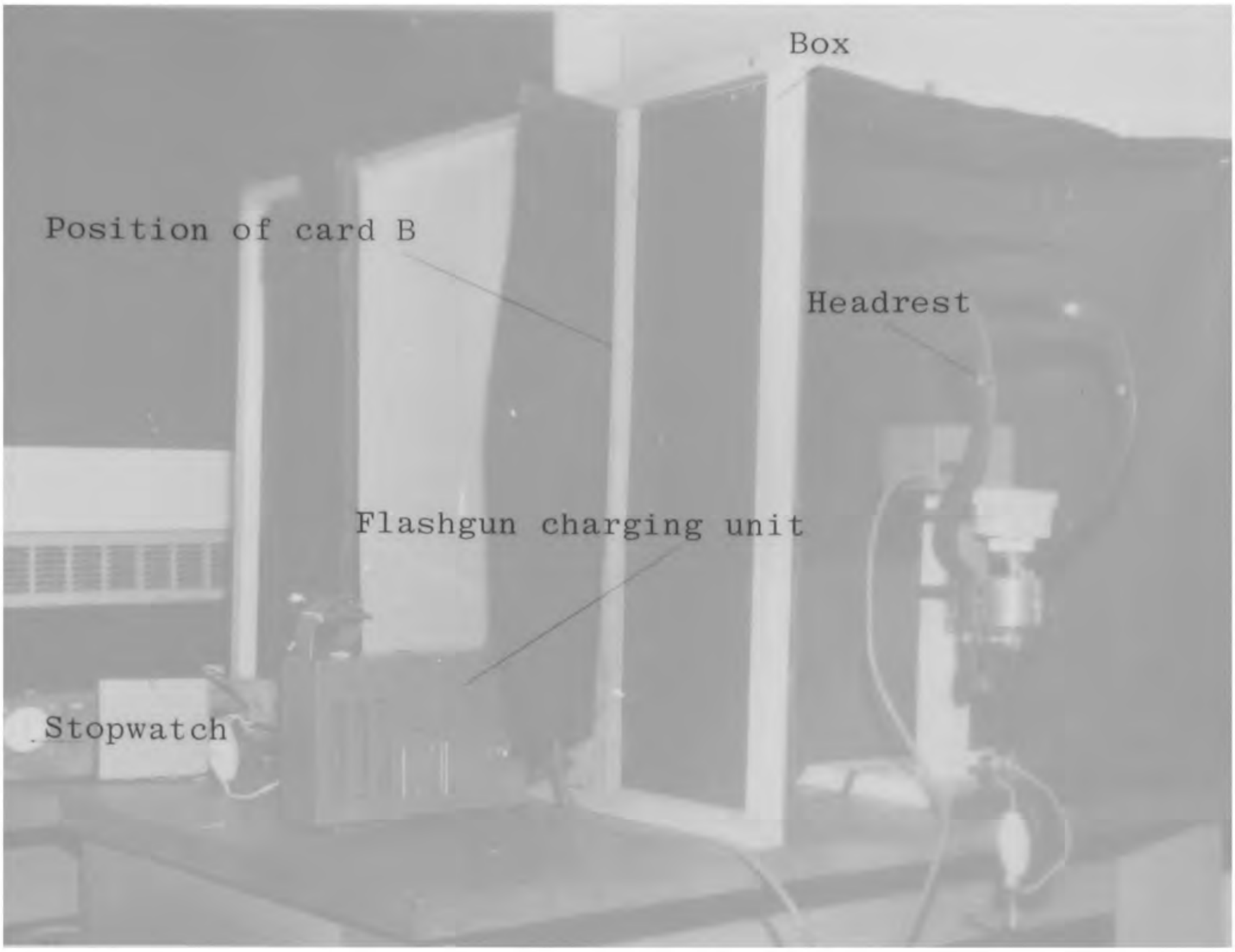


__Figure 3.7__ The apparatus

Stimulus holder

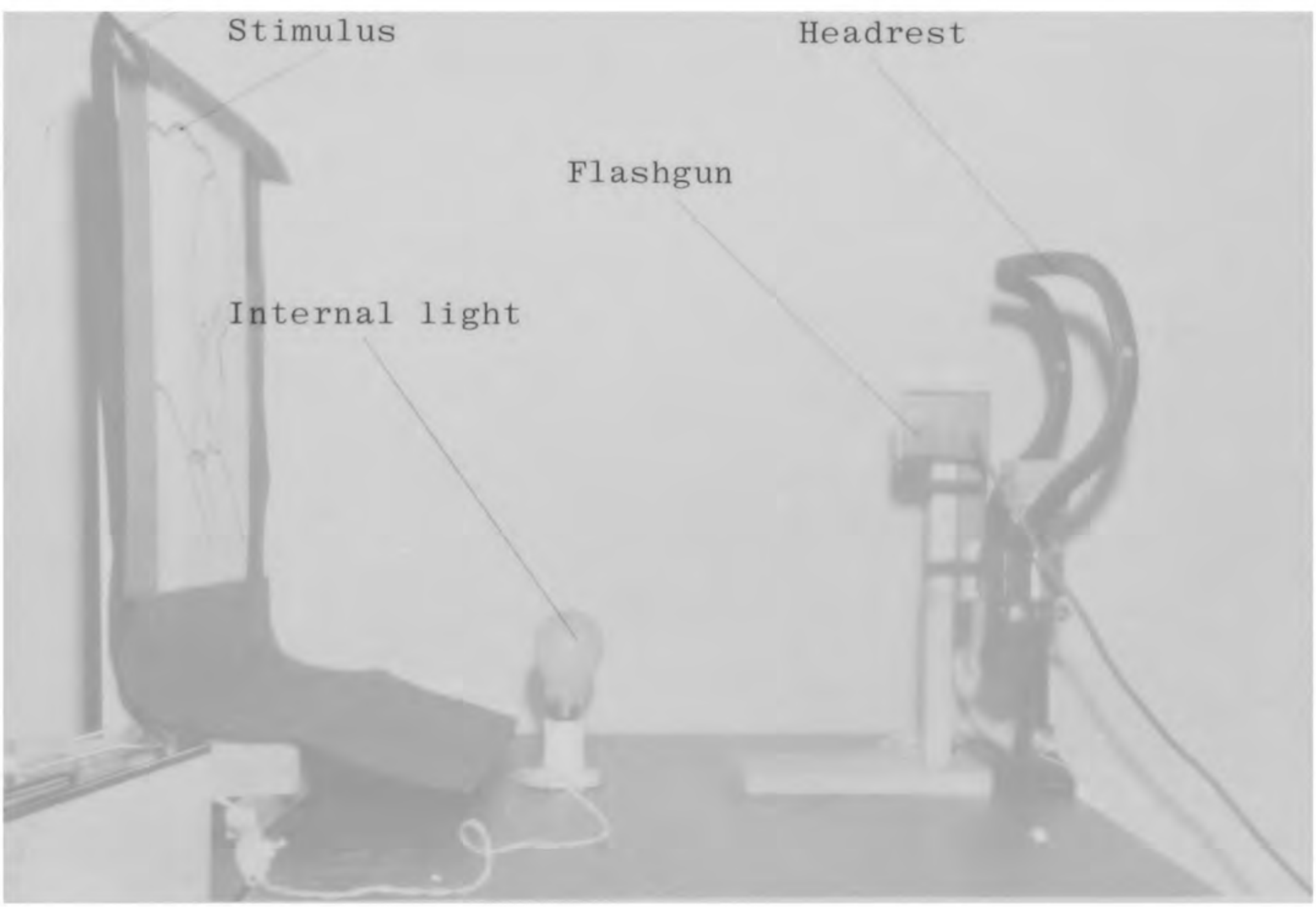


__Figure 3.8__ Component layout inside the 'box'.

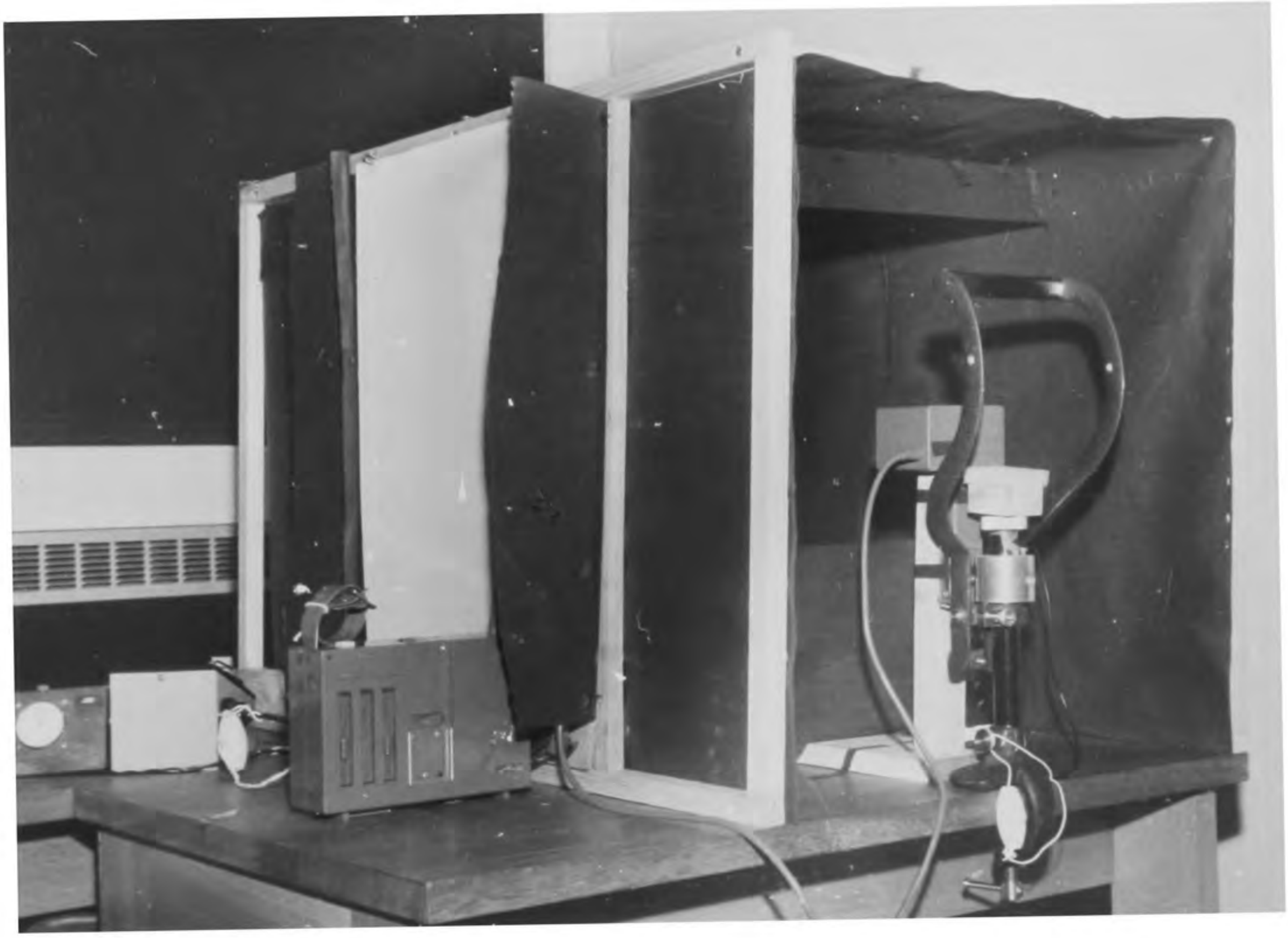


Figure 3.7 The apparatus

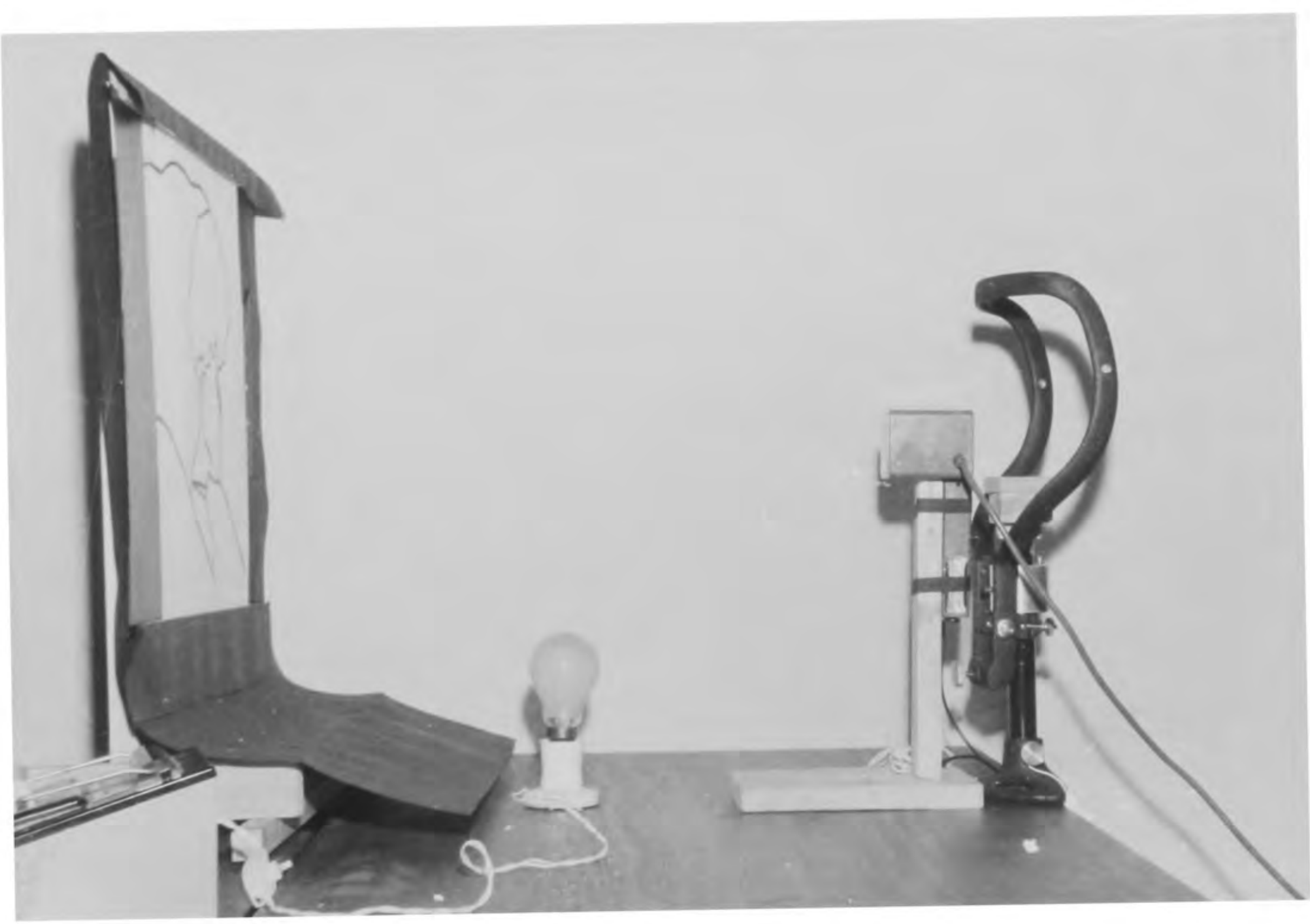


Figure 3.8 Component layout inside the 'box'.

at the centre of the stimulus. Both an intervening sighting aid and a mark on the centre of the stimulus holder were used in a no-parallax method to attain this. The following instructions being read:-

> "This is a headrest (indicated) and this is a flashgun (indicating the flash head) which I want you to operate later by pressing this button. Now if you put your chin on the chin-rest and tell me when these (indicating the sighting aid and the mark on the stimulus holder) are at the same height."

On completion card B was then introduced so obliterating S's view of the box interior. The room lights were turned off and S dark adapted for at least 5 minutes. During this time stimulus S_1 was mounted in the holder and the fixation spot positioned on it. When the side of the box had been replaced the internal light was briefly turned on so as to increase the luminosity of the spot and the flashgun was charged.

S was then instructed:

> "In a few moments you will see a luminous green spot. I want you to fixate this spot with both eyes open - of course, you will only be able to see it with your left/right eye (as appropriate for the S). When you have fixated the spot I want you to press the button and as soon as the flashgun goes off, close both your eyes gently and then tell me what you see. Any questions?"

Card B was then removed and S asked if he could see the spot. Upon confirmation he was then told to press the button when he was ready. S then reported what he saw. He was then instructed to ignore any changing colours in the afterimage, to wait until the stimulus appeared as a black line drawing on a white background and to simply report "what it was a picture of." Card B was introduced again and stimulus S_2 positioned on the holder. After at least 2 minutes to allow the first afterimage to disappear the following instructions were read:

> "I want you to do the same this time. After the flash, try to keep your gaze steady at the position where the fixation spot was before the flash - this will help you to see the picture clearly. (Card B was then removed after the internal light had been briefly turned on and off). Can you see the spot? ......O.K. Flash when you are ready."

This procedure was repeated for the first 5 presentations with at least a 2 minute interval between each. This interval being longer if a S reported that the previous afterimage had not completely faded. The first 3 stimuli were S_1, S_2, and S_3 respectively. The fourth and fifth stimuli for half the Ss were AL then AR (using a fixation position at the centre of the stimulus - spot position X (in Figure 3.5), the other half of the Ss received stimuli AR then AL with the same fixation position. All Ss responses were met with a non-committal "O.K." from E.

After these 5 stimuli had been presented the room lights were turned on and S shown a photograph (size 10 cms x 13 cms) of Boring's ambiguous figure and asked "can you tell me what this is a picture of?" If S only reported one aspect, then he was further asked "Can you see anything else?" Both aspects were then verbally elaborated for the S until he could readily perceive both and alternate between them.

The descriptions of each aspect were modelled after those used by Leeper (1935,pp64-65) and were as follows:

> "The picture can, in fact, be seen in two ways. It looks either like a young woman or like an older woman. The young woman is looking away over her shoulder so that her left cheek hides most of her face. The tip of her nose and eyelash can be seen but her mouth and eyes are hidden. Her left cheek and left ear are clearly visible as is her chin. A heavy fur collar is round her shoulders and on her head is a headscarf. The old woman is looking to one side so that her face is shown in profile. She has a large Roman nose, shrunken lips and a protruding chin which is almost hidden in the fur collar of her coat. Her left eye is clearly visible and you can make out the eyelash of her right eye. Her left ear and part of the side of her face is hidden by a headscarf."

For half the Ss the old woman was described first.

This procedure was then repeated, this time presenting S with stimuli AR and AL on the other side of the experimental room - some 190 cms away. The S was instructed:

> "These are two line drawings of the figure I have just shown you. In one the two possible faces are looking to the right hand side and in the other they are looking to the left hand side. Can you see both of the figures in these line drawings? I want you to look at these for a few minutes until you feel you can easily see both."

When the S could readily alternate between the two aspects on the line drawing the room lights were then turned off. S was then allowed to dark adapt again for some 5 minutes when the following instructions were read:

> "I am now going to present you with one of the pictures I have just shown you. I want you to tell me if you can perceive both aspects."

S was first presented with either AR or AL, using the same afterimage technique as before and fixation position X, then with the alternative stimulus.

S was then instructed:

> "Now I am going to show you a series of pictures like those you have just seen and in each case I want you to tell me whether it is a picture of a young or an old woman. I want you to tell me which it is as soon as you can clearly see the positive afterimage. Any questions?"

18 stimulus presentations were then given. 16 of these were of either stimuli AL or AR using each of the predetermined 15 fixation positions, the sixteenth one being a randomly chosen repeat condition of one of these positions. The order of

the conditions was chosen for each S by first determining the presentation order of the fixation positions using random number tables and then randomly assigning stimuli AL and AR to these such that eight presentations were of AL and eight were of AR. Stimulus OR or OL (using fixation position 1) was presented halfway through the series and again at the end (using fixation position 3). All Ss resposes were timed from the flashgun discharge to the verbal report of the appearance of the positive afterimage.

3.6.6. Results

The familiarisation stimuli. The three stimuli S_1, S_2 and S_3 each elicited descriptions of their positive afterimages. S_1 was described as the letter'H'or as'rugby posts', S_2 as the letter 'M'and S_3 as'H' or 'rugby posts' with an'extra line'.

First line drawing presentation. The responses obtained upon the first presentation of the ambiguous line drawing where Ss reported the appearance of the positive afterimage were categorised as young or old woman. All Ss described it as a woman's face, a young woman response being scored for a response similar to "woman looking away over her shoulder" and old woman for a response of the type "woman with a big nose."

Ten Ss were each initially presented with stimulus AL yielding 6 YW and 4 OW responses and ten with stimulus AR giving 7 YW and 3 OW responses. Thus, each stimulus was perceived with a preference for reporting YW, there being no difference between the two stimuli with respect to the proportion of responses attained, ($\chi^2=0$ NS). Eleven Ss responded as the same aspect to both the stimulus cards - 4 males responding as OW and 7 females giving 6 YW and 1 OW responses. Considering the first presentation of both stimuli AL and AR to each S then stimulus AL received 10 YW and 10 OW responses with AL achieving 11 YW and 9 OW responses (Sign test: p = 1.0, N.S.).

Photograph and line drawings. The photograph of Boring's figure was readily perceived as depicting both aspects. The majority of Ss had seen it before. On presentation of stimuli AL and AR after the photograph, with the room lights on, Ss had no difficulty in perceiving the stimulus cards as line drawings of this photograph. Some Ss reported that the left facing card was more like the YW than the other. This was probably related to the fact that the photograph was also left facing. All Ss were able to alternate between the two aspects with both the photograph and the line drawings.

Afterimages. After the above conditions all Ss reported the ability to perceive both aspects in

	Male Total		Female Total		Overall Total	
Fixation Position	OW	YW	OW	YW	OW	YW
1	0	10	0	10	0	20
2	2	8	2	8	4	16
3	5	5	4	6	9	11
4	2	8	3	7	5	15
5	1	9	0	10	1	19
6	7	3	5	5	12	8
7	6	4	5	5	11	9
8	6	4	7	3	13	7
9	6	4	8	2	14	6
10	8	2	5	5	13	7
11	9	1	9	1	18	2
12	6	4	8	2	14	6
13	8	2	7	3	15	5
14	6	4	6	4	12	8
15	9	1	6	4	15	5

Table 3.1 Male, female and overall number of YW responses for each fixation position.

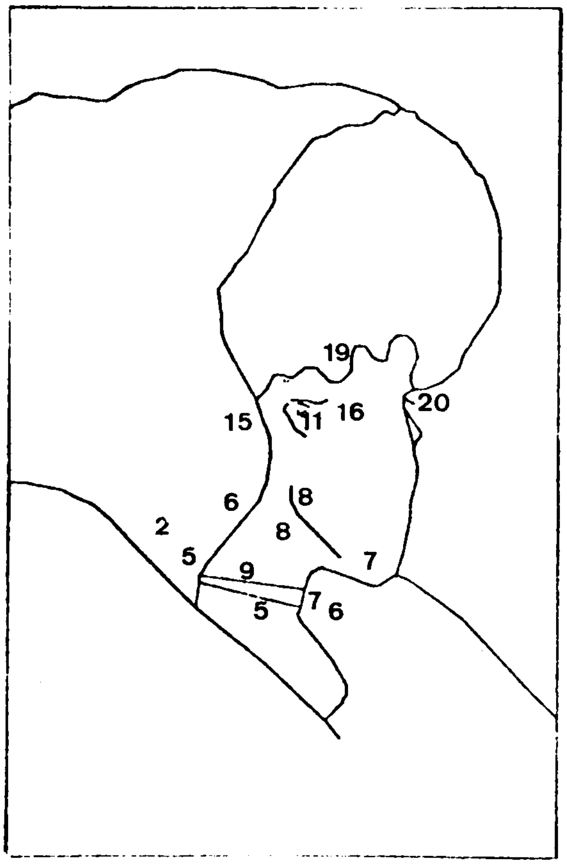


Figure 3.9 The total number of YW responses at each fixation position.

(a) (b) (c)

Figure 3.10 The 3 stimulus areas.

the afterimage (i.e. alternate between them) when instructed to do so using fixation position X. No S reported both aspects in the subsequent 18 experimental conditions.

The individual data for the different conditions is shown in Table A.1 (Appendix A). In all cases the repeated condition yielded the same response.

Male, female and overall responses per fixation position are shown in Table 3.1. Applying Fisher's exact probability test to examine differences between male-female responses per fixation position yielded no significant differences between the two sexes ($p > 0.05$ in all cases).

Taking an indicator variable of 1 for a YW response and 0 for an OW response the individual data for the 20 Ss on the 15 fixation positions was then analysed using Cochran's Q test which proved significant ($Q = 83$, $p < .001$). Thus, the different fixation positions did alter the responses to the stimuli. The overall number of YW responses per fixation position is shown in Figure 3. 9 where these are superimposed over the appropriate fixation position in the picture.

Stimuli OL and OR yielded predominantly OW responses. For fixation position 1 these were 17 OW and 3 YW responses and for fixation position 3 there were 18 OW and 2 YW responses. Both of these are significantly different (Sign test, $p < .001$ and $p = .02$ respectively), from those corresponding fixation positions on stimuli AL and AR.

All Ss responses were timed from the flash discharge to the verbal report. This was merely to check that the response did not immediately follow the flash, in which case the response would not be to the positive afterimage. These times ranged from 6 - 12s.

3.6.7. Discussion

The three stimuli S_1, S_2 and S_3 were used to familiarise Ss with both the appearance of afterimages and with the experimental technique. All Ss reported these stimuli appropriately. S_1 was reported as 'H' or 'rugby goal posts,' S_2 as 'M' and S_3 was reported as 'H' with an extra line.

After presentation of these 3 stimuli Ss would have some form of set to expect a letter-like stimulus, yet when stimulus AL or AR was then presented all Ss perceived it as a woman's face. Half of the Ss were initially presented with AL and half with AR, there being no significant difference in responses obtained to each stimulus and thus the stimuli were not differentially biased with respect to each other.

Before presenting the 18 experimental conditions Ss were shown a photograph of Boring's ambiguous figure, followed by the two experimental stimuli, line drawings of this figure. The purpose of this was to acquaint Ss with both aspects and thus attempt to remove any systematic bias on behalf of a S to perceive only one aspect. Using the photograph both aspects were verbally described if any S had difficulty in perceiving them. Ss then viewed the line drawings, all Ss at this stage being able to alternate between both aspects in these drawings. Ss had no difficulty with alternating with either the left or right facing versions. The line stimuli were presented some distance from S to prevent him perceiving the small pinholes.

Ss were then presented with stimuli AL and AR under afterimage viewing conditions with a central fixation spot. They were instructed to report if they could perceive both aspects in the afterimage, all Ss reported this ability. This demonstrated that the size of stimulus did not preclude the perception of either aspect as well as showing that when instructed to do so all Ss could alternate the afterimage of the stimulus. No S reported such alternation in the experimental conditions when they were instructed to report the appearance of the line drawing in the positive afterimage. This is despite the proximity of fixation position X and the experimental fixation position 3. (Figure 3.5).

Altering the fixation position does affect the resultant perception of the picture (Figure 3.9).

The number of YW responses increases as the fixation position approaches the YE element whereas the number of OW responses increases for fixations near the M element of the picture.

An explanation of these results could then be proposed on the basis of emphasising the almost exclusive importance of foveal vision. Assuming that this is a main determinant of selective visual attention. Thus, it could be argued that the picture is composed of a general facial outline common to both aspects and that the response of YW or OW is mainly determined by which element (YE, E/EC, C, M) is more in foveal vision. If these elements themselves are biased in the sense that fixation near a particular element is more likely to elicit perception of one aspect than the other then a spatial distribution of proportions of young or old woman responses would be attained. The assumption is that as a result of the pre-training the S is able to fairly readily perceive either aspect. Both schematic maps representing either aspect are available to him. Which aspect he reports being mainly determined by the element or elements more nearly in foveal vision than any other element. The former element is selectively attended to which then triggers a particular schematic map. These elements are predicted to be differentially weighted or biased towards either aspect thus effectively determining the S's response.

If the YE element is biased toward YW perception then fixation near this would produce a higher percentage of YW responses. This would seem to be the case as fixation in a similar position on a stimulus (OL or OR) not containing this element produced predominantly OW responses. This shows that it is not just the fixation position which is affecting which aspect is reported but fixation location and the presence of a particular element. If the mouth element were more biased toward the old woman aspect then fixation near this would be more likely to produce OW responses. Fixation near the E/EC or CL (elements which may be construed as representative of either aspect) would then be expected to produce more equivocal perception of both of the aspects.

This type of bias could be predicted from consideration of the meaningfulness of such elements. The YE element for the YW constitutes both her nose and eyelash, as such it then determines the direction of this face so that the E/EC is more likely to be construed as an ear. The M element is the mouth of the old woman, thus constituting a meaningful part of the face of this aspect, whereas for the YW it is a neck band, possibly a less important constituent. The cheek line (CL) is part of the nose of the OW or cheek of the YW. The E/EC complex, however, is a very meaningful conglomerate element which is important to both aspects, constituting either the old woman's eye or the young woman's ear.

The problem with an interpretation of this kind is fourfold. Firstly the arbitrary definition of two elements as being of importance and the other two being of less importance. Secondly, and related to the first, is the assumption that whereas 'an eye' (YE element) is of importance for one aspect a similar element, E/EC when construed as an eye, is not equivalently predicted to be important for perception of the old woman. A third problem is that it is simplistic in emphasising foveal vision only.

A fourth problem is that the data does not fully support such an explanation. Fixation near the YE element does produce solely YW responses. However, fixation at position 5 produces a very similar proportion of YW responses . Fixation near the mouth does produce more OW responses, but does not produce the most extreme OW response. Position 11 elicits this, where none of the elements selected are foveally viewed. Fixation positions near the CL or E/EC elements produce a proportion of both OW and YW responses in a manner as would be predicted by such an explanation.

An alternative explanation for the effect of altering fixation location could be proposed which would emphasise the role of particular circumscribed pictorial areas (i.e. Gestalten) with which certain elements may be associated.

Thus, the facial area A,B,C,D,E in Figure 3. 10(a). constitutes the face of the old woman aspect with the four elements being particular component facial features. In contrast the young woman may well be represented by a smaller facial area such as that bounded by the cheekline (area A,B,E in Figure 3.10(b)) or bounded by the mouth element itself (Figure 3.10(c)). As such the mouth and cheekline would function not as elements but as part of the outline. Closure has been reported in stabilised images and this could occur with the cheekline to form a line BE, although it was not reported after the present experiment by any S.

If it was the case that the YW aspect was then represented by a smaller figural area than that of the OW this may be a reason why Boring's ambiguous figure is predominantly reported as representing YW. That is the smaller figural area is being reported as being dominant, a finding in agreement with that of Rubin (1915); discussed in section 2.2.1). If this was so then responses to the stimulus with one or both of these two elements (M and CL) absent and fixation in the upper part of the figure would be predicted to be more OW than obtained when such elements were present. Fixation lower in the picture, which produces more OW responses and which are hypothesised to be based upon interpretating the M element as the mouth of the old woman, would be more difficult to predict.

By this latter explanation the effect of altering fixation position would be that the particular Gestalten involved would be largely determined by where the S is fixating.

The present experiment does not provide enough information to choose between these alternative explanations. In the next experiment the effects of removing the M and CL elements was investigated in order to test between these two possible accounts.

3.7. EXPERIMENT 2.

3.7.1. Introduction

The previous experiment demonstrated that altering the fixation location prior to painting the afterimage of the ambiguous outline stimulus did affect the proportion of YW or OW responses obtained. A possible explanation for this involving selective visual attention and area of stimulus fixated was proposed which involved interpretation of the four pictorial elements. The effect of the presence of absence of one of these elements (YE) at two fixation positions was determined. An alternative explanation emphasised the possible role played by the M and CL elements as boundaries of a Gestalt.

The present experiment set out to study the effect of presence or absence of the mouth (M) and cheek (CL) elements. It was, therefore, a test between these two hypotheses. Two of the previous fixation positions were used, these being positions 2 and 7. Position 2 is located near the two elements YE and E/EC while position 7 is located between the M and CL elements, being nearer the former.

According to the first proposed explanation, the main determinant of the response was due to the element more nearly in foveal vision, then no effect of altering the two elements M and CL should be found for position 2 while for position 7 some effect should occur. It was hypothesised that the M element was a main determinant of OW perception and thus absence of this element should lead to an increase in YW responses for this latter fixation position. The cheek element (CL) was proposed not to have such an effect on determining the response and so the presence or absence of this element should not affect the proportion of young or old woman responses at the lower fixation position.

Fixation location itself was predicted to affect perception of the ambiguous figure in that more YW responses were predicted to occur for position 2 than for position 7.

An alternative explanation for the results of the previous experiment was also proposed involving the YW aspect being represented by a smaller Gestalt than the OW aspect. The CL and M elements were proposed in such an instance to function not as elements but merely as part of the outline. Thus, in the absence of these elements a greater proportion of OW responses should be obtained when fixating in the upper part of the figure, i.e.in the absence of the elements that produce the necessary Gestalt area representing the YW aspect then the OW response should be found more often. With fixation in the lower part of the picture the M and CL elements are part of the overall OW face and so their absence may increase YW responses.

In Chapter 2 arguments were proposed for the choice of an ambiguous rather than a reversible perspective figure in this research. The second part of the present experiment involved a Necker cube using the same afterimage technique. Having demonstrated that different fixation positions affect the response obtained to an ambiguous figure then this effect should possibly also generalise to a reversible perspective figure.

The decision to use an ambiguous figure was partly determined by the response problems with such figures (i.e. possibility of multiple aspects being reported and not just the two alternative aspects). It was hypothesised that altering the fixation location on this figure should affect whether the Necker cube was perceived to be in the 'near face down' or the 'near face up' version. Although this is reported separately it was carried out using the same Ss after they had performed the experiment with the ambiguous figure.

3.7.2. Part 1. The Ambiguous Figure

3.7.3. Subjects

Twenty first year undergraduate psychology students served as Ss. 10 male and 10 female.

3.7.4. Stimuli

Two stimuli were constructed in a similar manner to stimuli AL and AR in the first experiment except that the M and CL elements were absent. These two elements were carefully cut out of black card. They could be attached to the stimuli so as to produce the four stimuli (A,B,C,and D) shown in Figure 3.11 which could be presented as facing either left or right.

A

M and CL absent

B

M absent

C

CL absent

D

M and CL present

Figure 3.11 The 4 stimuli with the 2 elements (M and CL) present or absent.

Each card contained two fixation positions equivalent to positions 2 and 7 in the previous experiment. Also stimuli S_1, S_2, and S_3 were again used.

3.7.5. Apparatus

The viewing box was redesigned. It was constructed from plywood and painted matt black both inside and out. An adjustable chin-rest mounted on a small optical bench at right angles to the S was positioned before the box. Rubber goggles were mounted in the front face of the box and these together with the chin-rest provided a fairly rigid head restraint. An aluminium occluder, painted matt black, could be slid across behind the goggles to obliterate the S's vision. In addition, two separate occluders were used to independently cut off either of the S's eyes. The flashgun, stimulus holder and the rest of the apparatus was the same as in Experiment 1. The front of the box with associated goggles and chin rest is shown in Figure 5. 7 . (The other equipment shown in this Figure were later modifications.)

3.7.6. Procedure

The procedure closely followed that of the previous experiment. After adjusting the chin rest so that S's eyes were level with the centre of the stimulus holder, eye dominance was established and the non-preferred eye-piece of the mask occluded. The flashgun button was pointed out and then the room lights were turned off to allow S to dark adapt. The following instructions were then given:

> "In a few minutes you will be able to see a small green luminous spot in front of you. I want you to fixate the spot and then press the button, this will cause the flashgun to discharge and you will see a brilliant flash. After the flashgun has discharged I want you to close your eyes lightly and then tell me what you see."

After the S had dark adapted (5-10 mins.) he was then sequentially presented with the three familiarisation stimuli being instructed to ignore colour changes and to verbally report "what it was a picture of" when the positive afterimage could be perceived. The phenomenon of fragmentation was pointed out to the Ss during these presentations:

> "You will find that the lines of the picture fade and reappear, sometimes you may not be able to notice them, this is called fragmentation."

In a similar fashion S was then presented with one of the versions of Boring's figure (stimulus D facing left or right) using the central fixation position X.

The room lights were then turned on and the photograph of Boring's figure presented. The S was asked if he had seen it before and to describe what the photograph represented. If initially unable to perceive both aspects then the experimenter verbally aided S to attain this ability. When able to alternate between both aspects then stimuli AL and AR from Experiment 1 were simultaneously shown some distance away. The subject was told:

> "Here are some old drawings I have of this picture. Can you see both the young and old woman in these? I want you to look at these cards for a few minutes and practice being able to see both aspects in them. O.K."

After 2-3 minutes the room lights were turned off again and S allowed to dark adapt. Two presentations of the full figure using fixation position X were then given with the S being instructed to report if he could perceive both the young and old woman in the positive afterimage. Half the Ss first receiving stimulus D facing right and then on the second occasion facing left. This order was reversed for the other half of the Ss.

The S was then instructed that he would receive a series of stimuli similar to the ones he had just seen and that he had to report whether it was a picture of the young or old woman as soon as he could clearly see the positive afterimage.

Eight presentations were then given using fixation positions 2 and 7 for each of the 4 stimulus conditions; each S receiving one presentation of each stimulus condition at each fixation position. Presentation order was randomised and the stimulus conditions were randomised across both left and right facing versions so that each S received four presentations for each direction. The technique of presenting these conditions to the S was such that the stimuli were mounted in the stimulus holder so that the fixation spot was always at the same position on the stimulus holder (its centre) and thus directly at S's eye level. This was to prevent the S being able to predict the appearance of the afterimage simply from the spatial position of the fixation spot. This was not considered a problem in the previous experiment as each S received 15 different positions and not, as here, 2 positions for 4 occasions each. The responses were timed from the flash.

All responses made by S during the experiment were met with a non-committal "O.K." from the experimenter.

3.7.7. Results

First presentation. After the familiarisation stimuli when the line drawing of Boring's ambiguous figure was presented as an afterimage all the Ss recognised it as a woman's face. Responses were interpreted as young or old woman in the same way as in the previous experiment. YW was reported by 13 Ss and OW by 7 Ss.

Photograph and line drawings. All Ss readily perceived both aspects in the photograph of Boring's figure and when subsequently shown the line drawings in the free viewing situation. Some of the Ss had seen the ambiguous figure previously.

Afterimages. When then presented with the stimulus so that it was perceived as an afterimage then all Ss reported the ability to alternate between both aspects using fixation position X. No alternation was reported in the subsequent experimental conditions.

The individual responses to the fixation positions are shown in Table A.2 (Appendix A). No S responded YW or OW to all the experimental conditions, although 2 Ss gave only one OW response each. This was despite them being able to perceive both aspects when shown the stimuli in the free viewing situation as well as being able to alternate on the afterimage when instructed to do so.

Figure 3.12 is a histogram showing the total number of YW responses to the stimulus conditions at both fixation positions. When these are considered in ascending order of number of YW responses then with one exception fixation position 2 produced more YW responses than did the alternate fixation position.

The individual data can be grouped together into appropriate matched pairs of stimuli to examine the effects of both fixation location and elements such that the difference between one pair and another is the presence or absence of one particular element at each fixation position. For

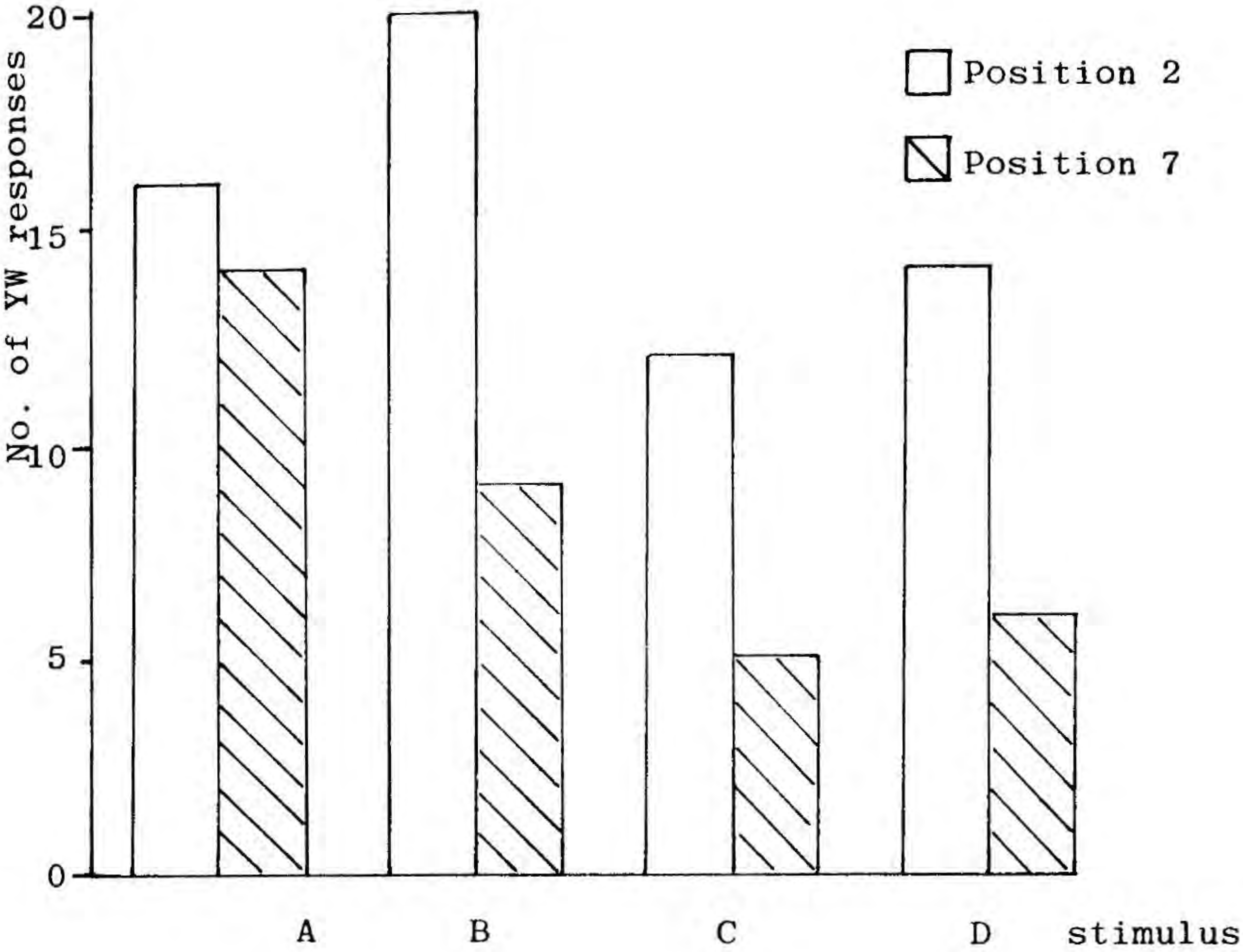


Figure 3.12 Total number of YW responses for each stimulus at both fixation positions.

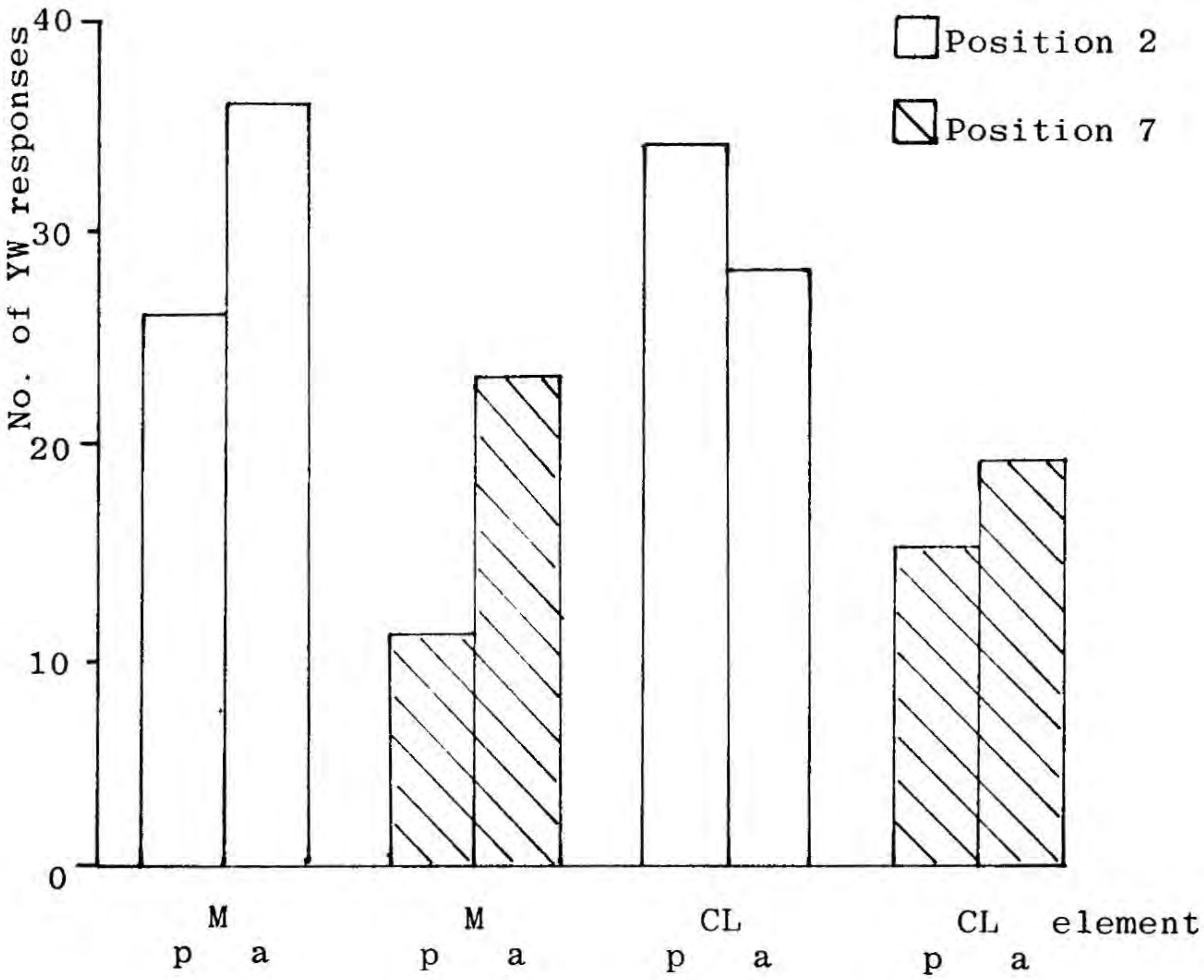


Figure 3.13 Total number of YW responses for the presence(p) or absence(a) of the 2 elements at both fixation positions.

instance, stimuli pairs A-B and C-D illustrate the absence or presence of the cheekline element which can be considered at either of the fixation locations. The dichotomous response of YW or OW was scored as 1 or 0 respectively. Presence of the M element significantly increased the number of OW responses (Wilcoxon matched-pairs signed-rank test: T = 10 for N = 12 Ss, $p < .02$ at position 2; T = 18.5 for N = 14, $p < .05$ for position 7; all probabilities are 2 tailed). Presence or absence of the CL elementwas not significant at either position (T = 11 for N = 10 at position 2; T = 22 for N = 11 at position 7, $p > .05$ in both cases) . Only at position 2 did its presence increase the number of YW responses.

Applying the same analysis to the effect of fixation position, where the fixation positions are compared across all the stimulus conditions, yields a significant difference (T = 9 for N = 18, $p < .01$). Fixation at position 2 increasing the number of YW responses. Figure 3.13 shows these results.

All Ss responses were timed from the discharge of the flashgun to the initial verbalisation of the reported percept to check that the response did not immediately follow the flashgun discharge.

The disadvantage of the Wilcoxon test is that possible interactions can not be investigated.

The binary data (YW = 1, OW = 0) forms a binomial distribution which is not suitable for treatment by Analysis of Variance. However it can be analysed as a quantal response model using GLIM (Baker and Nelder, 1978) in which interactions can be studied. This is a statistical program package for generalised linear models. The raw data was first transformed using the logit transformation (Cox, 1970).

The method of using this analysis involves first fitting a null model (this is a simple model, typically not fully accounting for the data) and then successively adding parameters (here there are three parameters, two pictorial elements and fixation position) and the interactions between each parameter. As each parameter is fitted the statistic called the scaled deviance and its degrees of freedom are estimated. The effect of adding a parameter is given by the difference in the scaled deviance having added it to that existing beforehand. This difference with the corresponding difference in degrees of freedom is distributed as χ^2 which gives an estimate of the usefulness of this parameter to the model.

Table 3.2 shows the effect on the scaled deviance produced by each additive parameter together with its corresponding degrees of freedom and χ^2 value. Significant effects were obtained for the fixation position and for the mouth ($p < 0.001$). None of the interaction effects were significant.

To provide a final model only the significant parameters of position and mouth were refitted (Table 3.3). When this was done the scaled deviance remaining after fitting the final model gave an indication of the adequacy of the fit of this model. The difference in scaled deviance between the initial null fit and this can be expressed as a percentage. In this way the model explains 79.4% of the data. The remaining scaled deviance can also be used to estimate the contribution to the data of using each S in all the conditions which may invalidate the use of χ^2 . In this way χ^2 was taken as 9.3 with 19 d.f. (for 20Ss, $p > .95$) which was not significant and so χ^2 use was not invalidated.

<u>Comparison with Experiment 1 results</u>. Stimulus D is the same as the stimulus used in Experiment 1. The proportion of young or old woman responses at the two fixation positions used in the present experiment can be directly compared with the proportions for the same positions in the previous experiment. Fixation at position 2 produced 14 YW and 6 OW responses compared to 16 YW and 4 OW responses in the previous experiment (χ^2 = 0.13, N.S.)

PARAMETERS	SCALED DEVIANCE	DF	χ^2	DF	p
Null Fit	45.1	7			
P	24.14	6	20.96	1	.001
M	9.3	5	14.84	1	.001
CL	9.17	4	0.13	1	NS
P x M	9.01	3	0.16	1	NS
P x CL	5.36	2	3.65	1	NS
M x CL	5.33	1	0.03	1	NS
P x M x CL	0.	0	0.	1	NS

P = fixation position
M and CL = elements
x = interaction

Table 3.2 The full GLIM analysis.

PARAMETERS	SCALED DEVIANCE	DF	χ^2	DF	p
Null Fit	45.1	7			
P	24.14	6	20.96	1	.001
M	9.3	5	14.84	1	.001

Table 3.3 The final GLIM model.

Position 7 elicited 6 YW and 14 OW responses with the proportion produced by the previous experiment being 9 YW and 11 OW ($\chi^2 = 0.43$, N.S.). The proportion of responses obtained in the two experiments are similar in both instances.

3.7.8. Discussion

On the first presentation of the ambiguous line drawing where Ss reported the appearance of its afterimage a higher proportion of YW responses was obtained. After the initial familiarisation with both the appearance of afterimages and the ambiguous stimulus all Ss could readily alternate the appearance of the afterimage when instructed to do so.

The experimental conditions entailed using two fixation positions which were selected from Experiment 1. Comparing the same stimulus conditions between the present experiment and Experiment 1 revealed no significant difference in proportions of young or old woman reponses. When the two fixation positions are compared over all the present experimental conditions a significant difference was found between these two locations such that position 2 elicited more YW responses and position 7 more OW responses.

As well as fixation position affecting the response, the presence or absence of the mouth and cheekline was important. Presence of the mouth significantly increased the number of OW responses obtained at both disparate fixation locations. The fact that this occurred at position 2 demonstrates that the M element does not act as a boundary of the Gestalt representing the YW aspect. Instead it demonstrates that for both positions this element was interpreted as the mouth of the OW aspect. This happened when the S was not fixating near such an element but rather some distance away.

The effect of the cheekline (CL) element was to increase (although not significantly) the proportion of YW responses at fixation position 2 when this element was present and to slightly increase the number of OW responses at the other fixation position.

The use of GLIM analysis confirmed the results of the Wilcoxon test and allowed possible interactions to be investigated. None of these interactions were important. For the lower fixation position, again no significant effect of CL was obtained, its presence eliciting more OW responses.

These results support those of the previous experiment by demonstrating that S's response to the figure can be determined by fixation location and picture elements.

Neither of the two fixation positions

produces true foveal perception of either of the two elements altered in the experiment. For both fixation locations the probability of a response was not only determined by the element nearest to the fixation position but also by elements some distance from the fixation position.

These findings cause problems for both of the main hypotheses being tested. Perception of the ambiguous figure is not solely determined by the nearest element and the 'bias' of that element. Neither is it solely a matter of the YW aspect being represented by a smaller Gestalt. The M element produced more OW responses at both fixation locations. It was, therefore, perceived as part of a Gestalt area making up the OW aspect when the S was fixating in the upper part of the picture. It would seem that more emphasis should be placed on the interpretation of elementsby peripheral vision rather than simply stressing essentially foveal vision.

The next experiment extended the present alteration of 2 elements to altering all 4 elements. This was to see if the present results could be replicated and also to further elaborate the role of elements which are more peripherally viewed.

3.7.9. Part 2. The Necker Cube

This was run as part of the previous experiment using 15 of the same Ss.

3.7.10. Stimulus

A Necker cube was drawn on a similar stimulus card to those in the previous experiment, being a black Indian ink line drawing on a white background. Overall size of the cube was 15.4 cms square. Each face of the cube was 10 cms x 10 cms with the diagonals 7.5 cms long and constructed at 45^o to the lower left face. Each line was 0.64 cms in width. Seven fixation positions were used as shown in Figure 3.14 .

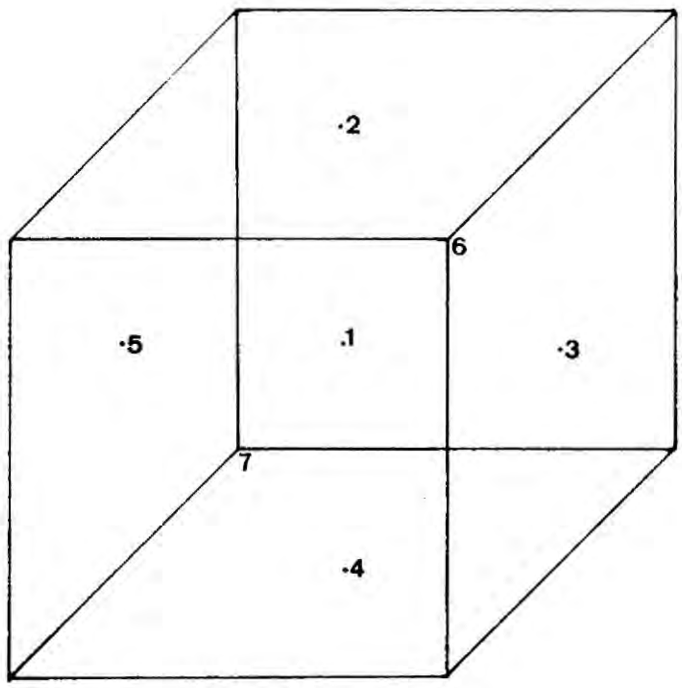
3.7.11. Procedure

In the previous experiment after the familiarisation stimuli the S was initially presented with the afterimage of the line drawing of the ambiguous figure. He was then presented with an afterimage of the Necker cube stimulus using a central fixation position. After having completed the previous experimental conditions, the room lights were turned on again and after a few minutes the S was shown a line drawing of the Necker cube. S was asked what the drawing represented. Both of the main aspects ('up' and 'down' facing cubes) were then verbally described if S had trouble seeing them. Two biased drawings of the Necker cube with either the near or far face shaded were then shown and S asked to call one of them an 'up' version and the other a 'down' version. He was then allowed to practice reporting 'up' or 'down', reporting on the unbiased Necker cube drawing and being able to refer to the biased versions if necessary. The room lights were then turned off and S instructed that after a few minutes to permit dark adaptation he would be presented with the cube stimulus which he would view as an afterimage in the same way as the previous figures and that he was to report 'up' or 'down' version as soon as it was clearly visible in the positive afterimage. Seven presentations of the Necker cube were given using each one of the 7 fixation positions in a randomly determined order for each S. The stimulus was presented so that the fixation position was always in the same spatial location for the S.

After completion of this part of the experiment S was again shown the biased drawings of the Necker cube and asked which one he had responded to as 'up' or 'down'.

3.7.12. Results

When initially presented with the Necker cube viewed as an afterimage, all Ss reported it as being a three dimensional cube. All Ss readily reversed their perception of the line drawing of the cube which was presented to them under normal



Fixation points 6 and 7 were at the two 'internal' corners.

Figure 3.14 The Necker cube and the 7 fixation positions.

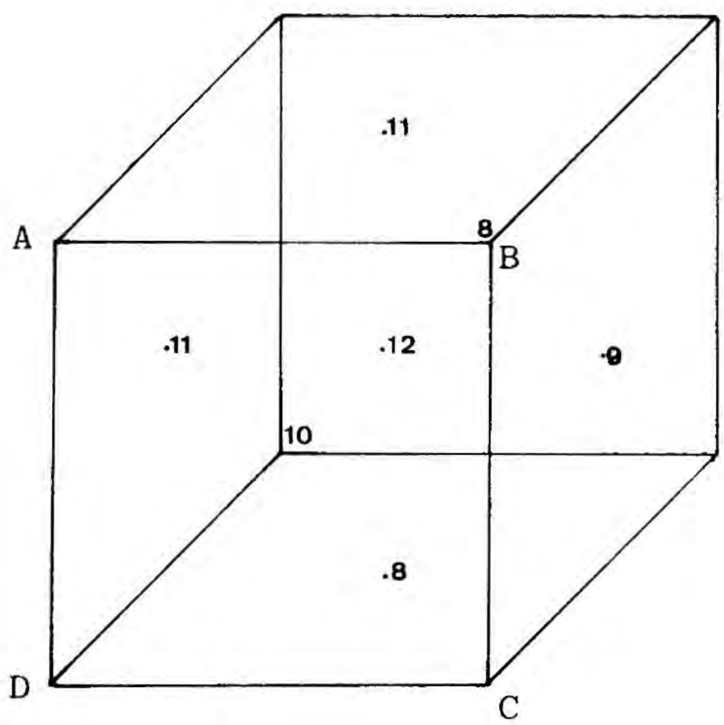


Figure 3.15 The number of occasions when the lower face (ABCD) was first reported at each fixation position.

viewing conditions. The number of times the lower face was first reported on the positive afterimage per fixation position is shown in Figure 3.15 . The individual data was analysed for an effect of fixation position upon the proportion of 'down' and 'up' responses. This yielded no significant results (Cochran Q test: $Q = 4.33$ for 6 d.f., $p > 0.5$).

All Ss reported reversal of the cube in the positive afterimage occurring after giving the response of 'up' or 'down'. For some Ss this occurred immediately on responding. Some of the Ss later stated that they had clearly perceived the cube during the flash discharge. All Ss had difficulty in verbally reporting with this figure.

3.7.13. Discussion

An attempt was made to extend the demonstration of the effects of different fixation positions, shown in Experiment 1, to the Necker cube. Ss readily reversed the appearance of the afterimage of the cube and all saw it as a three dimensional cube drawing when first presented with it. The ready ease with which Ss reversed this figure was notable when compared to Boring's ambiguous figure. No significant effect of fixation location upon dominance of either of the two aspects of 'up' or 'down' was found. The predominant response of perceiving the lower face as nearer (i.e. the down response) was obtained for all positions. The main difficulties with this figure were both this response stereotype and the rapid ease of reversal when viewing the afterimage. With afterimages of Boring's figure, alternations of aspect were not reported for the afterimages except when the Ss were specifically instructed to note them. This points to a specific difference between the two types of stimuli.

The ease of reversal thus seriously questioned the validity of the Ss' reports with the Necker cube and for this reason this part of the experiment was discontinued after 15 Ss.

3.8. EXPERIMENT 3.

3.8.1. Introduction

Having demonstrated the effects of the presence or absence of two of the elements this experiment extends this to study the effect of altering all four elements. The design follows that of the previous experiment with the two fixation positions (2 and 7) again used. Altering all four elements gives rise to 16 possible stimulus conditions as shown in Figure 3. 16

Experiment 2 confirmed that fixation position affected the response obtained as did the presence of the M element, the cheekline (CL) having no significant effect. These results were taken to indicate that elements which were not near the fixation position could affect the response to the stimulus. The present experiment alters all 4 elements to further examine this proposal.

It was hypothesised that similar effects to those of the previous experiment would be found with more young woman responses predicted for position 2 than for position 7. The presence of the old woman's mouth (M) should increase the number of old woman responses. Experiment 1 demonstrated the effect of the YE element in that fixating very near it produced predominantly YW responses, whereas, the same fixation location but using a stimulus without this element produced mainly OW responses. A similar finding occurring for fixation near the E/EC. Thus, it was hypothesised that the effect of this element (YE) would largely determine the number of YW responses found. Variation in the presence or absence of the E/EC was predicted to produce little effect on the responses obtained.

3.8.2. Subjects

Twenty undergraduate students. 10 male and 10 female.

3.8.3. Stimuli

Eight stimulus cards were constructed as previously described so as to be left and right

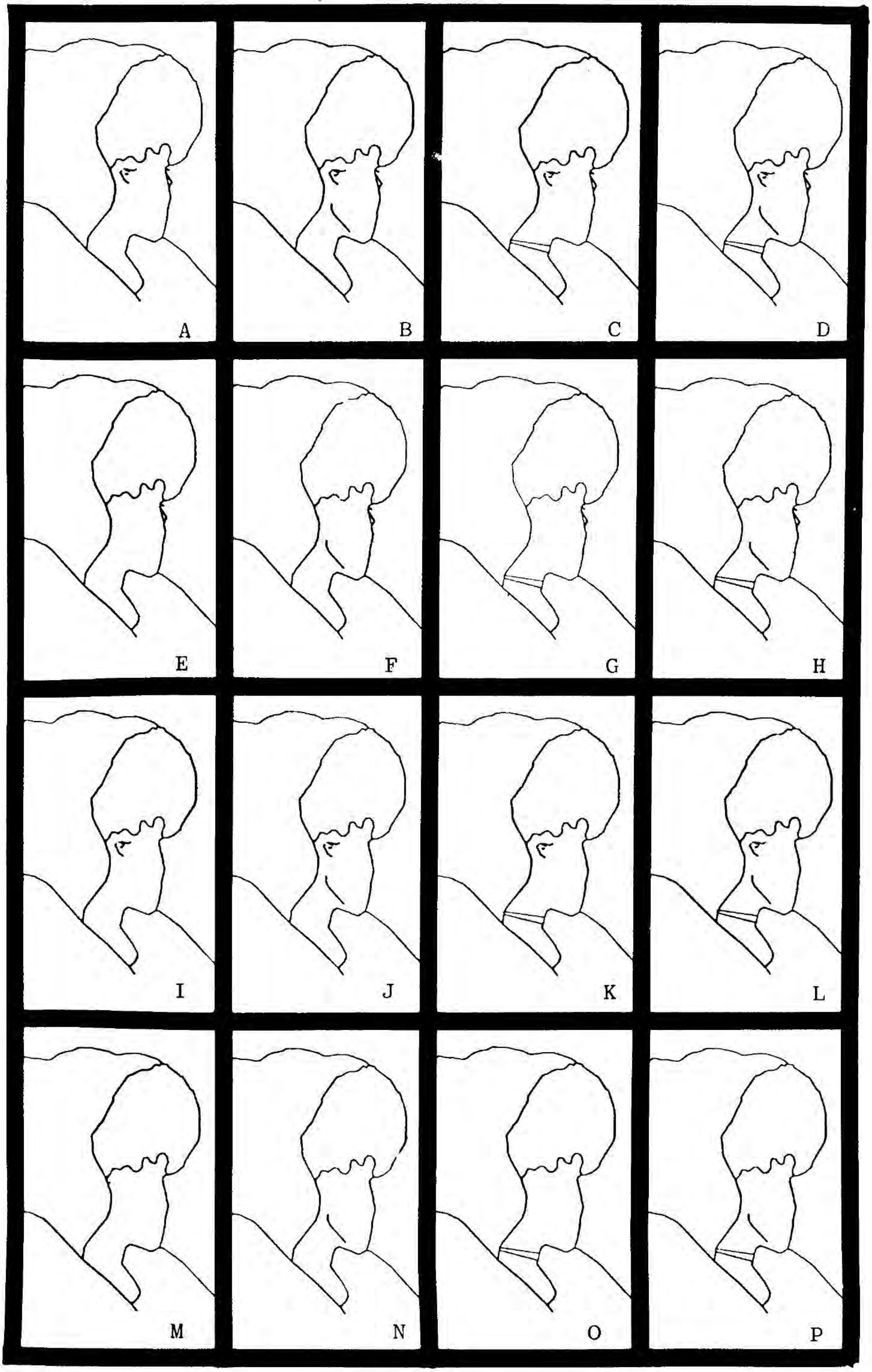


Figure 3.16 The 16 stimulus conditions.

facing versions of the following conditions: both YE and E/EC elements present; both these elements absent; only YE present; only E/EC present. To each of these stimuli could be added the M or CL elements (as were usedin Experiment 2), thus making a total of 32 experimental conditions (16 different conditions with the picture facing right or facing left). The same fixation positions as in Experiment 2 were used. The familiarisation stimulus from the previous experiment was used in accustoming Ss to afterimage appearance.

3.8.4. Apparatus

This was the same as for Experiment 2.

3.8.5. Procedure

The experiment was run in two separate sessions with a day between each session.

Session 1. This closely followed the procedure used in the previous 2 experiments. After being dark adapted for several minutes Ss were familiarised with the phenomenon of afterimages using stimuli S_1, S_2 and S_3 and then with the full version (i.e. all 4 elements present) of the ambiguous line drawing. Fragmentation of these afterimages was discussed with the S as in the previous experiment. With the room lights on S was then shown the photograph of Boring's ambiguous figure and asked if he had seen it before and what the picture represented. The two possible aspects were then verbally elaborated.

The two (left and right facing) versions of the ambiguous line drawing with all 4 elements present were then shown, Ss being asked if they could perceive both aspects in these stimuli and being allowed to practice alternation for a few minutes. The room lights were then turned off and S allowed to dark adapt again. Then the full line drawings were presented using the central fixation position (X) with the S being asked if he could perceive both aspects.

The S was then told he would receive a series of presentations of stimuli similar to the ones he had just been shown and that all he had to do was to report whether the positive afterimage of the stimulus resembled the young or old woman.

S was then given 16 presentations of the experimental conditions, these being randomly ordered for each S as in the previous experiments between left and right facing presentations and then again randomly assigned to either this first presentation session or to the second. As in the previous experiment the stimuli were presented so that the luminous fixation spot always appeared in the same spatial location with respect to the S.

Session 2. The S was first shown the photograph of Boring's ambiguous figure and asked if he could readily perceive both aspects. The left and right facing full line drawings were then presented to S with similar instructions. Two afterimage presentations of the full left and full right facing versions were then given using fixation position X. The remaining 16 experimental conditions were then given with the instructions as in Session 1. Two repeat conditions of stimuli which had been shown in the first session to that S were included amongst these so that there was a total of 18 presentations.

Fourteen Ss also received two additional presentations of stimulus conditions D and L (Figure 3.16) but with the fixation at spot position 1 as in Experiment 1. Again these stimuli were presented so that the fixation spot was in the same spatial position relative to the S and these conditions were presented randomly within the other series of stimuli.

3.8.6. <u>Results</u>

<u>Initial Presentation</u>. On first presentation of the line drawing of Boring's figure such that Ss reported the appearance of the afterimage, one S reported "wavy lines", 13 Ss reported YW and 2 OW with 4 others simply reporting a face without further elaboration to enable categorisation into a young or old woman response.

The number of YW responses obtained for each of the 16 stimulus conditions is shown in Figure 3.17 .

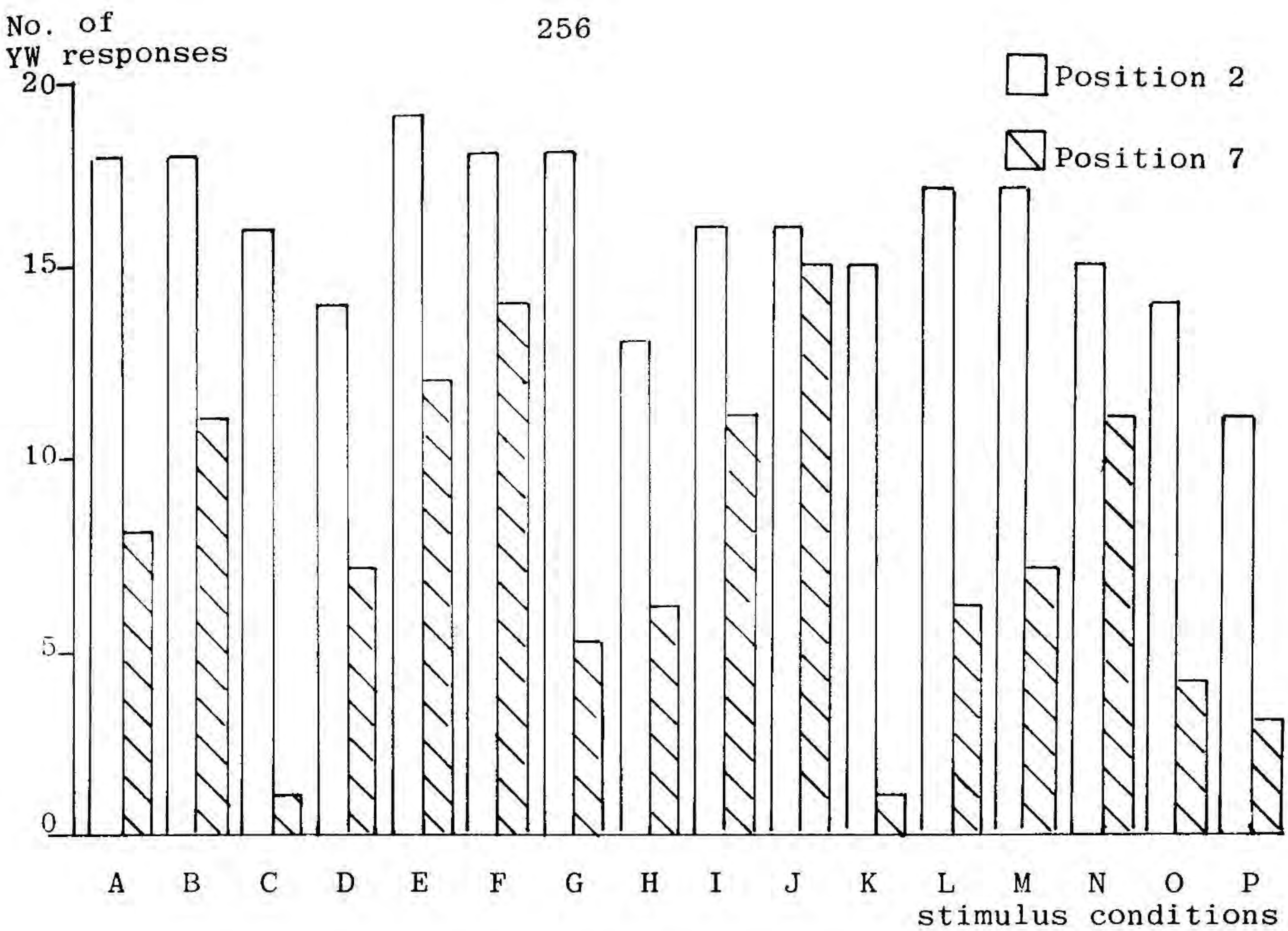


Figure 3.17 Total number of YW responses obtained at both fixation positions for each stimulus.

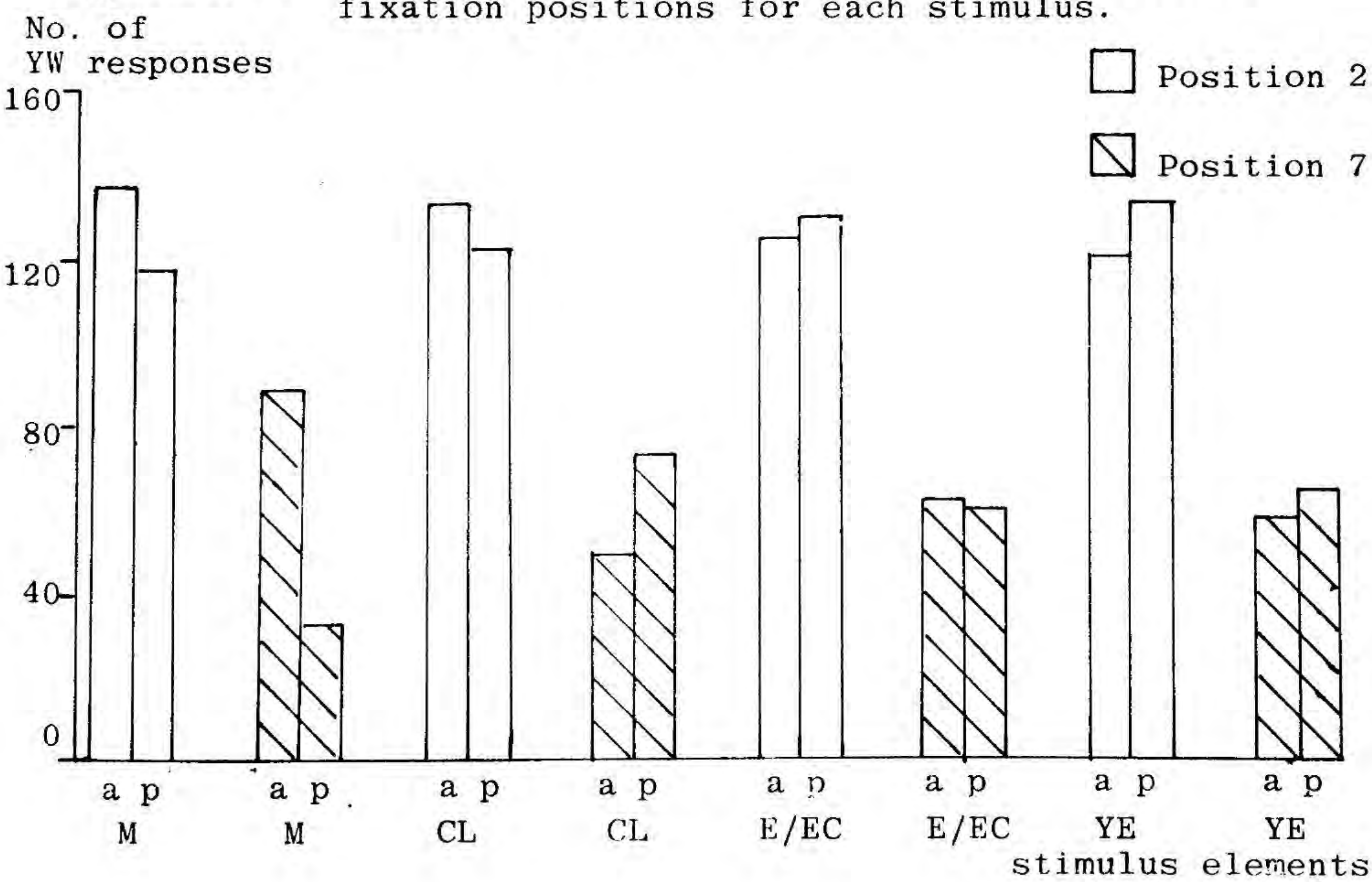


Figure 3.18 Total number of YW responses for the presence (p) or absence (a) of the 4 elements at both fixation positions.

Comparison with Experiment 1. The response at each fixation position to stimulus condition D can be compared to that obtained for the same fixation positions in Experiment 1, as this is the same stimulus. Here 14 Ss reported YW at position 2 and 8 reported YW at position 7. In Experiment 1 these numbers were 16 and 9 respectively. The difference between the two corresponding conditions is not significant (χ^2=0.13 for position 2, χ^2=.04 for position 7).

Comparison with Experiment 2. Conditions A, B,C and D were also the same as the four stimulus conditions used in Experiment 2. Comparing the same condition in each experiment yielded no significant difference in proportions of young or old woman responses ($p > 0.05$ in all cases. χ^2 test or Fisher's Exact Probability Test where appropriate).

Afterimages. The total number of YW responses obtained for the presence or absence of each element at each fixation position is shown in Figure 3. 18. The same responses were obtained for the 2 conditions in session 2 which were repeats of conditions given that S in the first session. Scoring a YW response as 1 and an OW response as 0 the stimulus conditions were then grouped together to examine the effect of fixation position and also the presence or absence of each element at each position. Presence of the M element when fixation position 7 was used significantly increased the number of OW responses (Wilcoxon matched-pairs signed-ranks test: $T = 1.5$ for $N = 16$, $p < .01$) its presence at the other position also increased the OW responses obtained ($T = 25.5$ for $N = 16$, $p < .05$). In contrast CL presence at position 7 increased the number of YW responses ($T = 7$ for $N = 14$, $p < .01$) whereas at position 2 its presence increased the number of OW responses, although not significantly ($p > .05$). Presence or absence of the YE or E/EC elements at either fixation positions did not produce a significant difference in responses although YE presence did increase the number of YW responses at both locations ($p > .05$ in all cases).

The proportion of YW responses to each stimulus fixation condition was also analysed using GLIM, after a logit transformation. The parameters of fixation position and all four elements were fitted together with all the 26 interactions as shown in Table 3.4 . Significant χ^2 values were obtained for fixation position and for the M element. The two factor interactions of: fixation position (P) x CL, P x M, E/EC x YE, and E/EC x CL were also significant. These interactions are shown in Figure 3. 19 . All these significant parameters together with the CL,

PARAMETERS	SCALED DEVIANCE	DF	χ^2	DF	p
Null Fit	206.4	31			
P	87.99	30	118.41	1	.001
M	42.76	29	45.23	1	.001
E/EC	42.68	28	0.08	1	NS
YE	39.62	27	3.06	1	NS
CL	38.18	26	1.44	1	NS
PxM	33.54	25	4.64	1	.05
PxE/EC	33.06	24	0.48	1	NS
PxYE	32.26	23	0.8	1	NS
PxCL	22.44	22	9.82	1	.01
MxE/EC	22.42	21	0.02	1	NS
MxYE	22.35	20	0.07	1	NS
MxCL	22.35	19	0.	1	NS
E/ECxYE	16.16	18	6.19	1	.02
E/ECxCL	11.62	17	4.54	1	NS
YExCL	11.10	16	0.52	1	NS
PxMxE/EC	9.58	15	1.52	1	NS
PxMxYE	7.43	14	2.15	1	NS
PxMxCL	7.21	13	0.22	1	NS
PxE/ECxYE	7.07	12	0.14	1	NS
PxE/ECxCL	7.06	11	0.01	1	NS
PxYExCL	6.42	10	0.64	1	NS
MxE/ECxYE	6.1	9	0.2	1	NS
MxE/ECxCL	3.87	8	2.27	1	NS
MxYExCL	3.86	7	0.01	1	NS
E/ECxYExCL	3.85	6	0.01	1	NS
PxMxE/ECxYE	2.26	5	1.59	1	NS
PxMxE/ECxCL	1.2	4	1.06	1	NS
PxMxYExCL	0.06	3	1.14	1	NS
PxE/ECxYExCL	0.06	2	0.	1	NS
MxE/ECxYExCL	0.	1	0.	1	NS
PxMxE/ECxYExCL	0.	0	0.	1	NS

P = Fixation Position
x = Interaction
DF = Degrees of freedom
PR = Probability
NS = Not significant ($p > 0.05$)

TABLE 3.4 The full GLIM analysis.

E/EC and YE elements (in order to give these interactions) were then refitted to provide the final model (Table 3. 5). An estimate of the goodness of fit of the final model is given by considering the difference in scaled deviance between that of the initial null fit and that left when the model is fitted. Expressing this as a percentage of the scaled deviance of the initial null fit. By this means the model explains 93.8 % of the data. An estimate of the contribution of using each S in all the conditions (which can be considered as a violation of the independance of the measures necessary for a χ^2 analysis) is given by taking the final scaled deviance as a χ^2 value for N-1 degrees of freedom where N is the number of subjects. This gives $\chi^2 = 12.71$ for 19 d.f. (N.S.) thus the use of χ^2 can be considered as valid.

The fourteen Ss who received the additional presentations using fixation position 1 all responded YW to stimulus D but for stimulus L only 8 Ss so responded, the rest reporting OW.

These responses can be compared to the Ss' responses in Experiment 1 to the similar conditions. In the first experiment all 20 Ss reported YW at presentation position 1 when YE was present but only 3 made the same response for that fixation position

PARAMETERS	SCALED DEVIANCE	DF	χ^2	DF	p
Null Fit	206.4	31			
P	87.99	30	118.41	1	.001
M	42.76	29	45.23	1	.001
YE	39.7	28	3.06	1	NS
CL	38.26	27	1.44	1	NS
E/EC	38.18	26	0.08	1	NS
P x M	33.54	25	4.64	1	.05
P x CL	23.7	24	9.84	1	.01
E/EC x YE	17.28	23	6.42	1	.02
E/EC x CL	12.71	22	4.57	1	.02

Table 3.5 The final GLIM model.

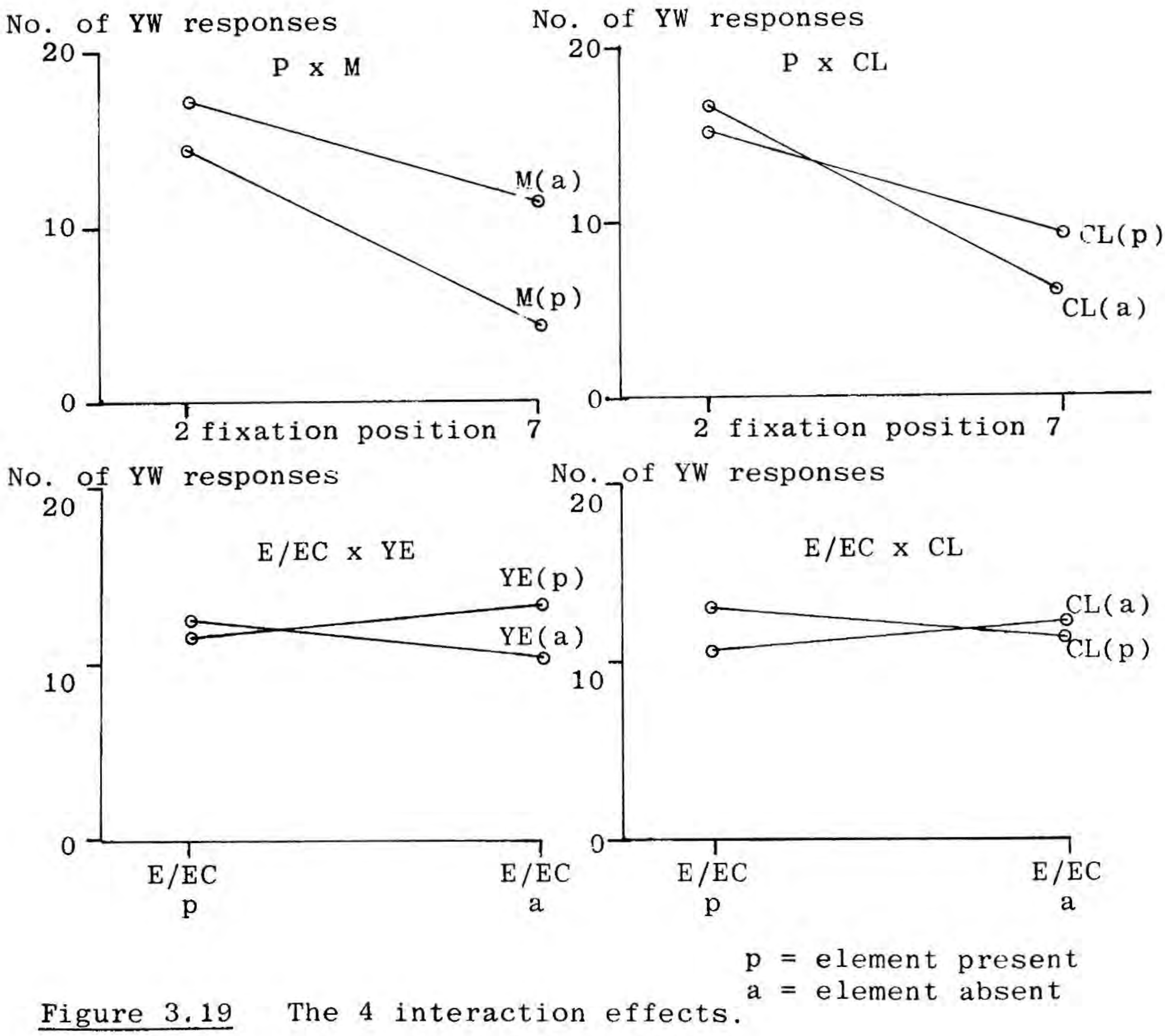


Figure 3.19 The 4 interaction effects.

when this element was absent. The latter result is significantly different (χ^2=24.89, $p<.05$) from the present one, whereas the former result is not.

3.8.7. Discussion

Experiment 2 studied the effect of altering two of the picture elements upon the response obtained for each of the selected two fixation positions. The present experiment extended this to examine the effects of all four elements at these two positions. The experiment was run in two sessions because the large number of experimental conditions would have meant a single session lasting over 2 hours. No significant difference was found between the present experimental conditions and those identical conditions from either of the two previous experiments.

Fixation position had a significant effect on the number of YW responses obtained, more responses being elicited by fixation position 2.

As in the previous experiment the M element had a great effect in that its presence increased the number of OW responses at both fixation positions. This effect being greater at the position nearer this element such that an interaction between fixation location and the M element occurred. No main effect of any of the other elements was found although interactions between them were important.

Presence of the CL element increased the number of YW responses at fixation position 7 whereas it decreased it at position 2. No such interactions between fixation position and the M or CL elements were found in the previous experiment.

The E/EC element interacted with both the YE and CL elements. YE presence increased the number of YW responses when the E/EC was absent having a slight opposite effect when the E/EC element was present. Presence of both the E/EC and the CL elements also resulted in more YW responses compared to when CL was absent although when the E/EC element was absent there was a smaller difference between them.

The hypothesised effect of the presence of the YE element in increasing the number of YW responses was found to occur at both fixation positions (as shown in Figure 3.18) but not to any significant extent. After the first 6 Ss had been run and this trend found in their results, it was decided to include the additional condition of fixating at position 1, using either stimulus D or stimulus L (i.e. with or without YE element present). The results of these conditions demonstrated that with the YE element present all 14 Ss responded YW (a similar result being found in Experiment 1 for the same condition). However, absence of the element did not result in as many OW responses as expected from the same condition in the first experiment. In the present instance only 6 Ss reported OW (out of 14 Ss) when the YE element was absent and fixation was at position 1, i.e. very near the element's actual location. Also in the first experiment fixation at position 3 had given rise to 18 OW responses when the YE element was absent. It had been because of these first experimental results demonstrating a major YW determining effect of the YE element that the present result of little effect of YE presence or absence upon the responses obtained was queried and why these extra conditions were added. It had been thought that the number of YW responses to fixation position 2 without YE present (stimulus L) would lie somewhere between those obtained in Experiment 1 for fixation positions 1 and 3. This was not the case. Here 17 Ss responded YW with this element absent and 18 gave the same response with it present.

These results support the hypothesis that the response to the figure is not solely determined by the nearest element to the fixation position. Rather they again demonstrate that the elements can be considered to be weighted toward either aspect (e.g. the M element is heavily weighted towards perception of the old woman aspect). The interaction effects further suggest that the response is determined by the sum of the weighted elements which are available both in the stimulus display and which can be attended to. Such visual attention has some limit which is primarily determined by fixation position.

The failure to find a significant main effect of the YE element may be due to the fixation positions chosen. YE presence at both positions slightly increased the proportion of YW responses, thus it was not the case that this failure was due to acuity (inability to distinguish the presence or absence of this element).

3.9. DISCUSSION OF THE AFTERIMAGE EXPERIMENTS

In this Chapter, 3 experiments are presented which use an afterimage technique to examine the contribution to the perception of a line drawing of Boring's ambiguous figure of fixation position and particular elements of the picture. A large stimulus display was used so that these parameters could be examined as proposed in the previous Chapter. The line drawing was derived to enable a good afterimage of the stimulus to be obtained. The lines constituting this stimulus were proposed to represent four facial elements which could be experimentally manipulated together with other lines making up a general facial outline.

An experimental procedure was used which first familiarised Ss both with afterimage appearance and with both aspects of the ambiguous figure.

In acquainting the Ss with both aspects, verbal descriptions of the appearance of each aspect were used with the S viewing a photograph of Boring's ambiguous figure. No attempt was made to visually indicate specific parts of the picture.

In all 3 experiments all Ss were able to alternate their response to the afterimage of the stimulus when fixation was at a central point on the stimulus display. This is taken to imply that the stimulus size did not preclude one or other aspect. The results of the experimental conditions in all 3 experiments further demonstrated that Ss could respond to both aspects with this size of stimulus.

A verbal response of which aspect was perceived in the positive afterimage was used throughout as this permitted Ss to both initially describe other afterimage phenomena as well as allowing them to possibly respond "neither aspect", although the latter never occurred.

The first experiment demonstrated that as fixation position moved more towards the YE element then the proportion of young woman responses increased. As fixation moved more towards the M element the proportion of OW responses increased.

Looking at particular areas of the stimulus, therefore, did affect which aspect was reported. This agrees with Hochberg's (1970a)proposal. Hochberg suggested that fixating in region i of Figure 3.2 (b) would elicit a YW response whereas fixating in region ii of the same Figure would produce an OW response. This is generally supported by the results of this experiment, although it is difficult to draw exact boundaries between two such distinct areas. For instance, the results of the first experiment would suggest that the area ii should encompass the M element more, also area i should encompass the E/EC. Instead of two distinct regions what is proposed here is that the stimulus consists of two overlapping regions which possibly are really only distinct at their 'extreme' positions of YE or M elements. It is proposed that the response is determined by attending to weighted elements. The response itself will be to the stimulus as a whole such that such weighted elements enter into a Gestalt. Altering the presence or absence of the YE element demonstrated that it was not solely fixation position that determined the response but the elements which are present.

The second and third experiments examined the effect of adding or removing the four elements from the general outline. In these experiments fragmentation of lines in the afterimage of the familiarisation stimuli was pointed out to Ss in an attempt to prevent them hypothesising that the absence of elements from the ambiguous figure afterimages was an experimental manipulation. From questioning the Ss after the experiment this was largely successful. Only two fixation positions were used which were selected so as to give fixation between the E/EC and YE elements or else fixation between the M and CL elements.

Results showed that the M element had a great effect in determining OW perception but that the YE element did not have a great effect in determining YW responses as predicted on the basis of the results from Experiment 1. Experiment 3 demonstrated that interactions between some elements and others, and also between some elements and fixation position were important factors.

Each of the 4 elements can be considered to be weighted to a greater or lesser extent towards each aspect (e.g. the M element appears strongly weighted towards the OW aspect). The response to the stimulus when presented in a stabilised fashion is, therefore, determined by the sum of the weighted elements available to the S at that fixation location. 'Available' here means that the S can attend to such an element. The location of the S's fixation position on such a large stimulus effectively controls which elements he could attend to. In Pritchard's (1958) experiment he found the limit of such attention on the Mach book figure to be 1-2^{o} visual angle. The present results demonstrated the effectiveness of the M element when fixation was at position 2, some 8-9^{o} visual angle away. The effectiveness of this particular element at such a distance may possibly be a function of its size as well as its utility.

Task demands appear to affect this useful field of view within which elements may be useful. Mackworth (1965) reported a useful area of 2^{o} in tachistoscopic studies where small objects and visual noise were present. Edwards and Goolkasian (1974) demonstrated useful fields of view of 10^{o} visual angle and Mackworth (1976) more recently found 6^{o} fields useful in a particular task.

3.10. SUMMARY

Afterimage studies have been carried out which support the hypothesis that the response of one particular aspect as figure in an ambiguous line drawing is a function both of fixation location and the elements available to the S at that location. These elements it is argued are biased in their representation of each aspect.

The next step is to investigate what effect altering these elements has upon the response to the line drawing in a free viewing situation as opposed to when fixation position is controlled by the experimenter. This work is presented in the next chapter.

CHAPTER 4

THE FREE VIEWING EXPERIMENTS

4.1. INTRODUCTION

In the previous chapter three experiments were presented in which a S's fixation position was controlled when viewing a relatively large stimulus. With the use of an afterimage technique the result of fixation near particular elements of the ambiguous figure was elucidated. It was proposed that a weighting could be attached to such elements. This weighting was suggested to represent how much each element contributed to (or was biased towards) either of the possible aspects. The effect of controlling fixation was proposed to result in the triggering of one aspect's schematic map rather than the other as a result of such weighted elements seen both foveally and para-foveally.

In the first experiment it was shown that as fixation position moved towards the YE element then the proportion of YW responses increased. However, in Experiment 3 where this element was either present or removed from the stimulus then it appeared to have a smaller effect than predicted in determining YW peception. In contrast the effect of the M element was to increase the proportion of OW responses, this being found for all three experiments. Altering the CL and E/EC elements did not have such an obvious effect upon the interpretation of the stimulus.

In all these experiments fixation position was determined by the experimenter. It is possible that these results may not generalise to a free viewing situation. In this chapter two experiments are reported which employed such free viewing to see if this generalisation did occur.

It was hypothesised that if the Ss were presented with a series of stimuli in which the previously determined four elements were altered then the response to the stimuli would be determined by those elements present in each stimulus. Specifically, it was hypothesised that the presence of the OW element would increase the proportion of OW responses, whereas the presence of the YE element would increase the number of YW responses. The presence or absence of the other two elements were predicted not to have such a great determining effect upon the response.

The first experiment reported in this chapter used a group of students as Ss. The second experiment used children of two age groups to see if any age related changes occurred in the perception of the ambiguous figure.

4.2. EXPERIMENT 4.

4.2.1. Introduction

The purpose of this experiment was to study the effects of the presence or absence of the four stimulus elements using a student population when fixation position was not controlled, that is, when Ss were allowed to freely view the stimuli.

The 16 stimulus conditions of the presence or absence of the four elements were used for this, together with 8 additional conditions. These latter stimuli contained a smaller 'old woman's mouth' element than was used in the previous experiment.

The second and third experiments had demonstrated that the M element produced an increase in old woman responses at the two selected fixation positions. This may possibly be related to the physical size of this element as well as its interpretation as a facial feature. The smaller mouth was modelled after the small mouth in the ambiguous version of Boring's figure as presented by Neisser (1967). It was hypothesised that if this element affected perception of the picture by its interpretation rather than its size then altering its size would not affect the proportion of OW responses obtained.

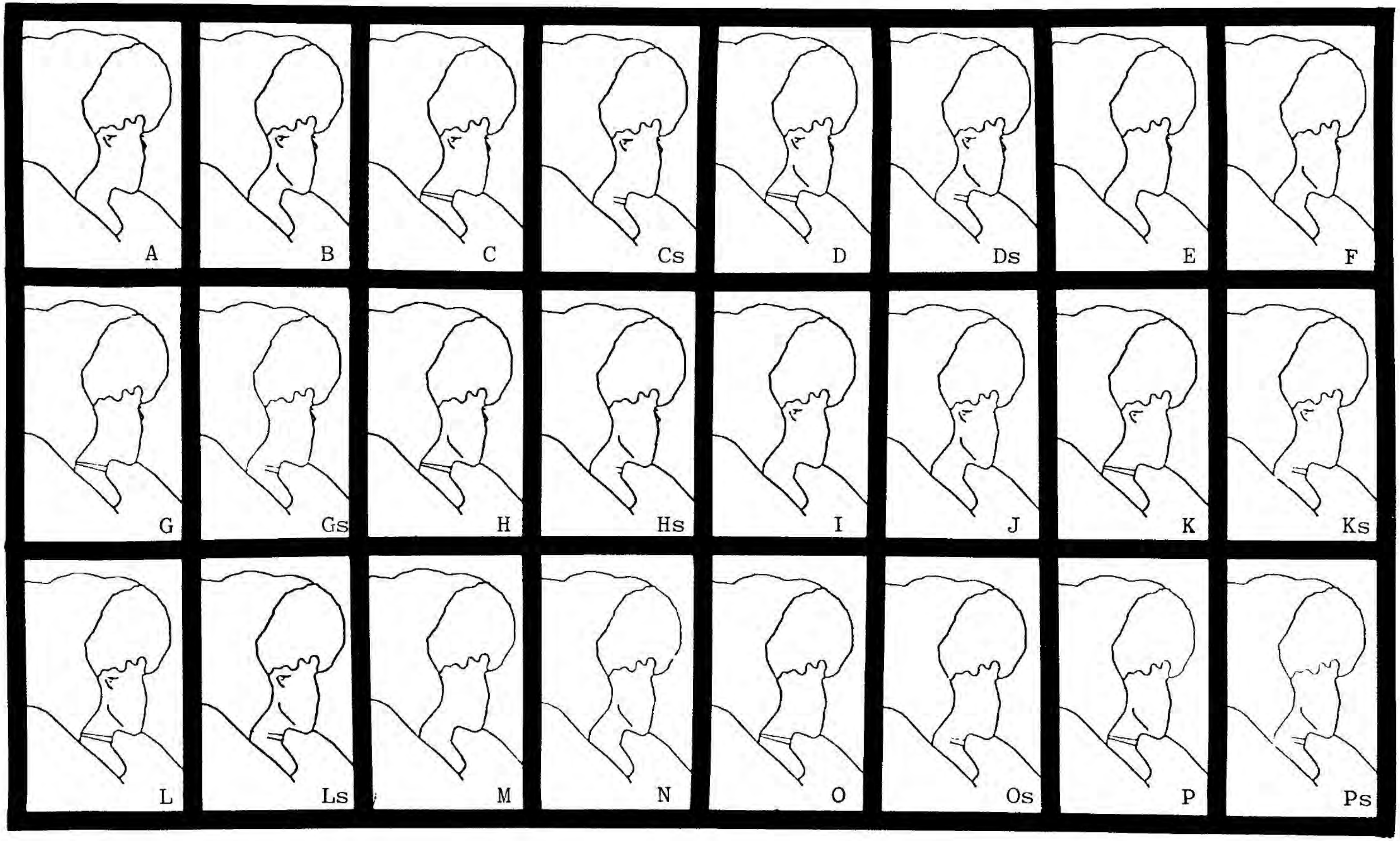
The first afterimage experiment found a major effect of the presence or absence of the YE element in determining the YW response. The presence of this element acting to increase the likelihood of this response and its absence decreasing it. The same experiment demonstrated that as fixation position moved towards this element then again the likelihood of this response was increased. In contrast altering this element in Experiment 3 had less of an effect. It was hypothesised that, in free viewing, the effect of this element in increasing YW responses by its presence would be increased. The other two elements, CL and E/EC, were predicted to have less effect on the interpretation of the picture.

4.2.2. Subjects

48 undergraduate students, 24 males and 24 females took part.

4.2.3. Stimuli

The 16 experimental conditions used in Experiment 3 were photographed and produced as prints, size 10 cms x 13 cms. The M element on the negatives of the 8 conditions containing this element was reduced in size by an equal amount and similar size prints made. These constituted the small-mouth conditions. The resulting 24 stimulus conditions (Figure 4.1)were produced in both left and right facing directions making a total of 48 stimuli. 24 of these (one of each condition) were selected using random number tables so that 12 of



<u>Figure 4.1</u> The 24 stimuli.

s = versions with a small M element

them faced left and 12 faced right. Four of these selected conditions were further randomly chosen to be represented by both directions. These being used as repeat conditions.

These 28 photographs were mounted on card of the same size and covered in clear plastic to prevent damage through handling. A small identifying letter was printed on the back of each card at the top left hand side.

4.2.4. Procedure

The experiment was carried out in the Ss' own rooms in the collegiate halls of residence. After each S agreed to take part in the experiment they were seated at their desk and presented with the pack of cards face down. They were then instructed to go through the pack turning the cards over one by one without making any response and to simply look at each card and then turn it over again before going on to the next.

The purpose of this was to familiarise the S with the different appearances of the line drawings used without firstly having given them any instructions as to what the stimuli represented. It also acquainted them with the procedure and the rate of performing the experiment. Ss were allowed to turn the cards over at their own speed, but in the subsequent part of the experiment this had to allow the experimenter time to note down both the response and card identifying letter.

The Ss were then shown a photograph of Boring's ambiguous figure of similar size to the cards and asked if they had seen it before and to say what it was a picture of. Both aspects were then verbally described to the Ss, as in the previous experiments, and they were then allowed several minutes to practice alternating between the two aspects with the photograph. When they reported that they could readily change aspects the following instructions were given:

> "The pack of cards which you have just looked through are line drawings of the same figure as the photograph. Some of these drawings may look more like one of the women's faces than the other. What I want you to do is to go through the pack again, turning one card over at a time and immediately naming which of the two faces it looks the more like. Having named it I want you to turn the card back over again before looking at the next one. Do this at your own rate. Do you have any questions?"

The pack was reshuffled and presented face down to the S. S then went through the pack turning each card over one at a time and naming it as young or old woman then turning it back over, so that at the end of the experiment the S was again faced with the inverted pack of cards. As the S went through the cards the experimenter noted the identifying letter of each card and the S's response to it. After doing the experiment Ss were questioned as to

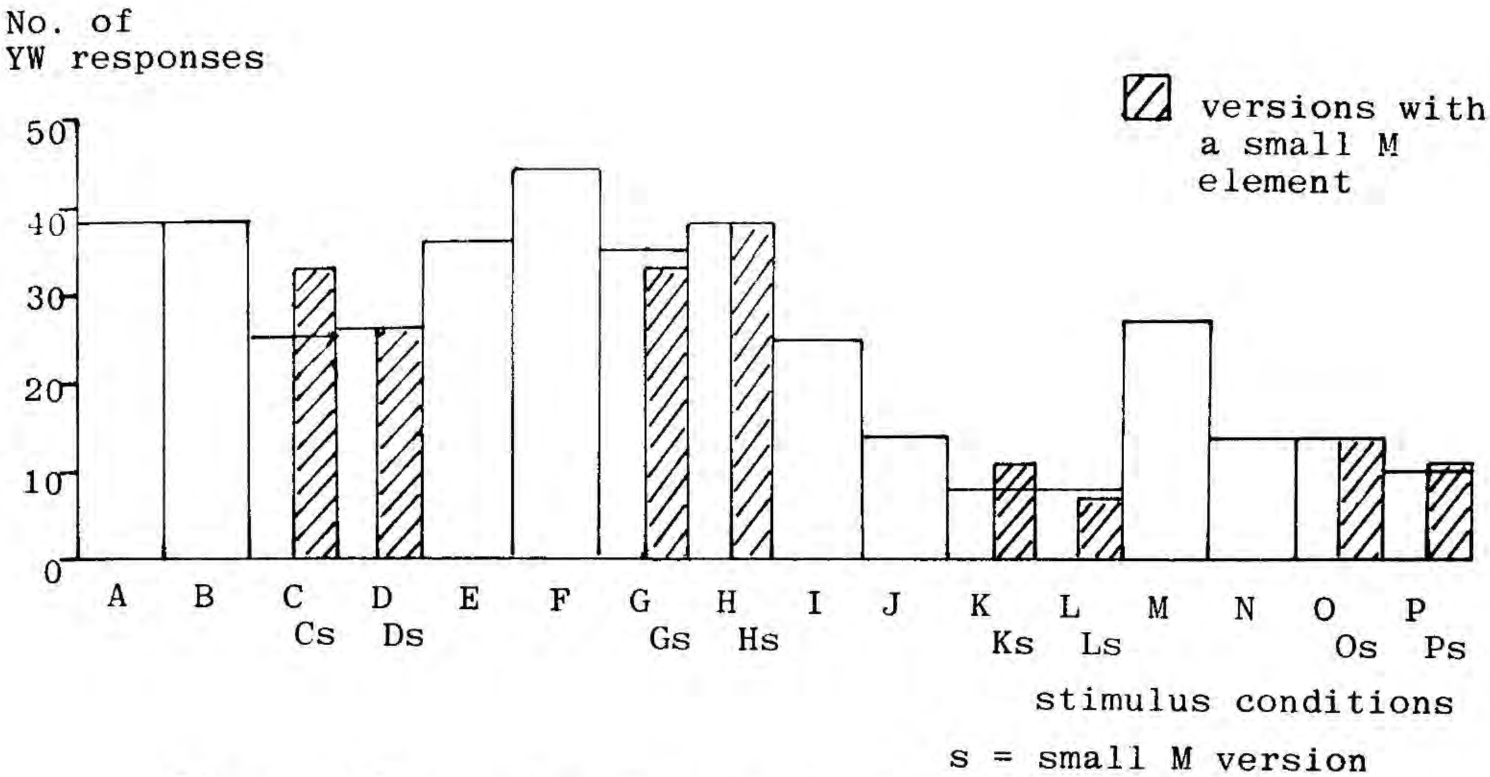


Figure 4.2 Total number of YW responses for each stimulus condition.

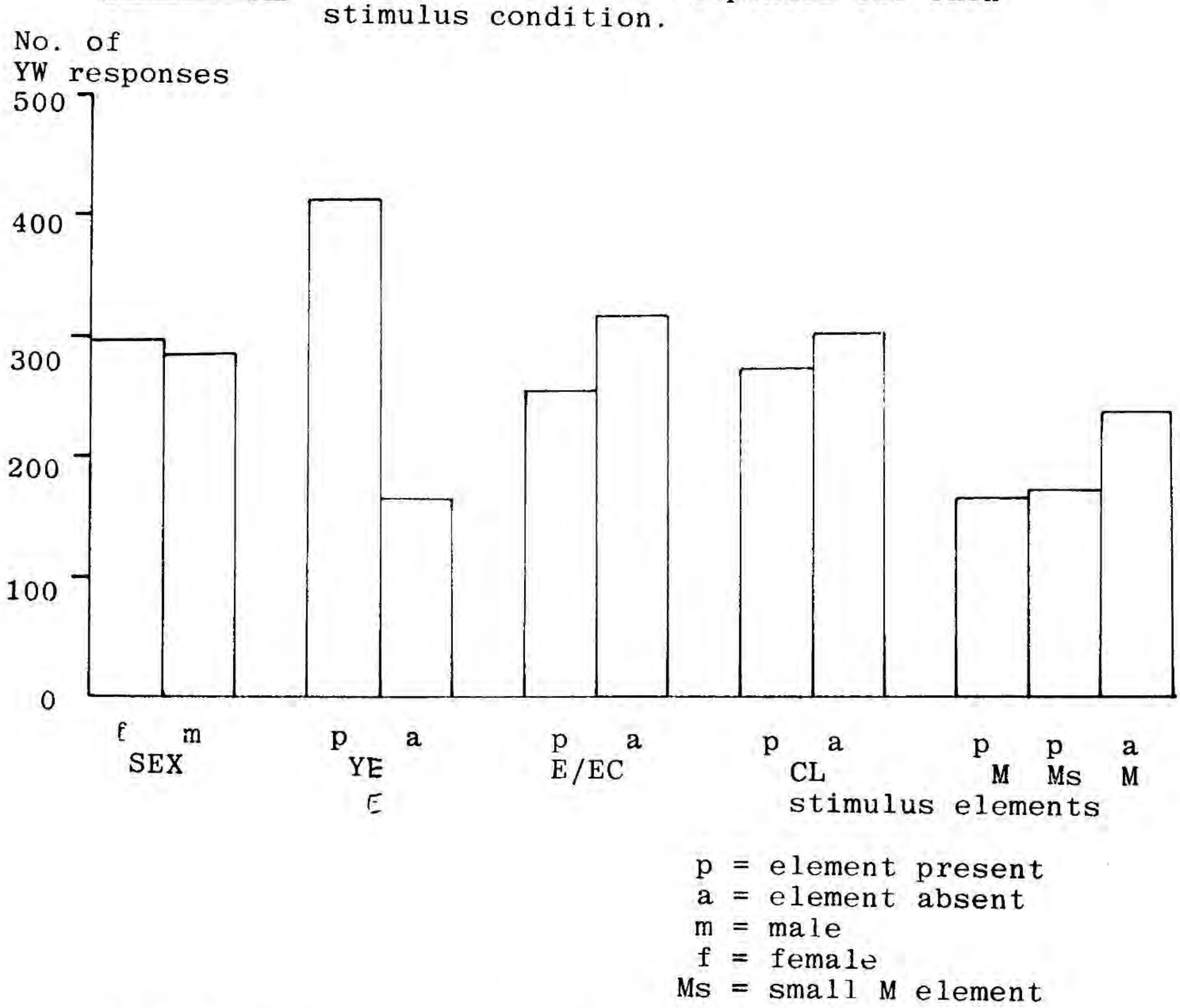


Figure 4.3 Total number of YW responses for each parameter.

what they thought determined their response and were then finally told the purpose of the work.

4.2.5. Results

The total number of YW responses for each condition is shown in Figure 4.2. The mean values are shown for the four conditions which were repeated, a similar proportion of YW responses was obtained for each of these. This data was analysed using the GLIM program with a logit transformation (Table 4.1). A null model was first fitted followed by the sequential addition of the five parameters of sex, M, CL, E/EC and YE as well as all possible interactions. The M parameter had three levels: large or small size and absence of this element. All the other parameters had two levels of presence or absence of that facial element. In the case of sex the two levels were male and female. Figure 4.3. shows the total number of YW responses obtained for each level of these parameters taken across all the stimulus conditions. From the GLIM analysis significant χ^2 values ($p < .001$) were obtained for the M, YE and E/EC elements by themselves and for the interactions ($p < .01$) of sex x YE and CL x YE (Figure 4.4.).

A final model (Table 4.2) was then fitted using only these significant parameters plus the sex and CL ones in order to obtain the two significant

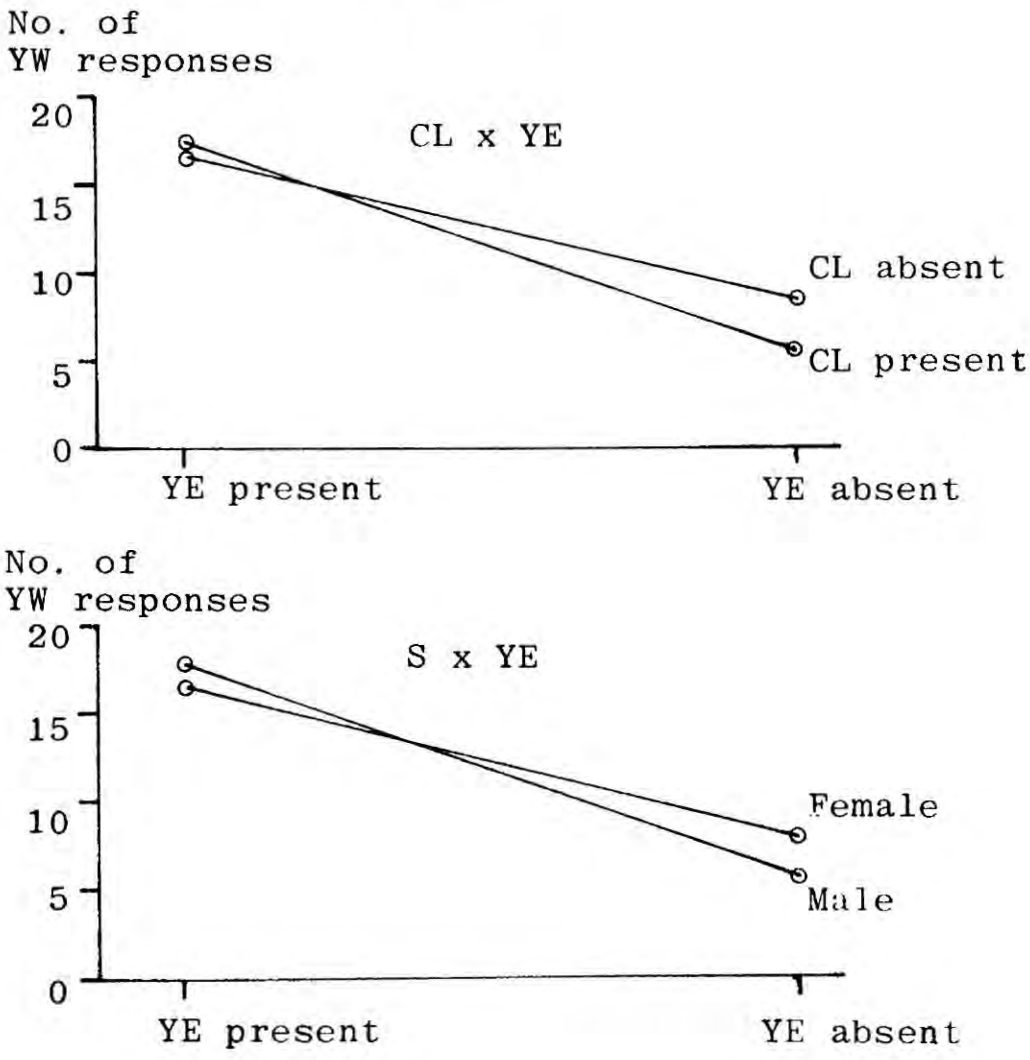
PARAMETERS	SCALED DEVIANCE	DF	χ^2	DF	p
Null Fit	334.3	47			
S	334.0	46	0.3	1	NS
M	301.7	44	32.3	2	.001
CL	299.5	43	2.2	1	NS
YE	72.5	42	227.0	1	.001
E/EC	59.09	41	13.41	1	.001
SxM	53.63	39	5.46	2	NS
SxCL	53.55	38	0.08	1	NS
SxYE	46.7	37	6.85	1	.01
SxE/EC	45.15	36	1.55	1	NS
MxCL	43.37	34	1.78	2	NS
MxYE	43.04	32	0.33	2	NS
MxE/EC	38.99	30	4.05	2	NS
CLxYE	30.52	29	8.47	1	.01
CLxE/EC	28.32	28	2.2	1	NS
YExE/EC	27.49	27	0.83	1	NS
SxMxCL	26.36	25	1.13	2	NS
SxMxYE	23.27	23	3.09	2	NS
SxMxE/EC	23.0	21	0.27	2	NS
SxCLxYE	22.87	20	0.13	1	NS
SxCLxE/EC	21.42	19	1.45	1	NS
SxYExE/EC	21.4	18	0.02	1	NS
MxCLxYE	17.24	16	4.16	2	NS
MxCLxE/EC	16.04	14	1.2	2	NS
MxYExE/EC	15.68	12	0.36	2	NS
CLxYExE/EC	12.14	11	3.54	1	NS
SxMxCLxYE	10.97	9	1.17	2	NS
SxMxCLxE/EC	9.93	7	1.04	2	NS
SxCLxYExE/EC	8.01	6	1.92	1	NS
SxMxYExE/EC	3.03	4	4.98	2	NS
MxCLxYExE/EC	2.79	2	0.24	2	NS
SxMxYExCLxE/EC	0.	0	2.79	2	NS

S = Sex
x = Interaction
NS = Not significant ($p > 0.05$)

Table 4.1 The full GLIM analysis.

PARAMETERS	SCALED DEVIANCE	DF	χ^2	DF	p
Null Fit	334.3	17			
S (SEX)	334.0	46	0.3	1	NS
M	301.7	44	32.3	1	.001
CL	299.5	43	2.2	1	NS
YE	72.5	42	227.0	1	.001
E/EC	59.09	41	13.41	1	.001
S x YE	53.25	40	5.94	1	.02
CL x YE	43.98	39	9.27	1	.01

Table 4.2 The final GLIM model.



S = sex

Figure 4.4 The 2 significant interactions of CL x YE and S x YE.

interactions. An estimate of the contribution of using each S in every condition was obtained by taking the scaled deviance left after fitting the final model as a χ^2 value. This was not significant (χ^2 = 43.98 for 47 d.f.). The final model explains some 86.8 % of the data.

4.2.6. Discussion

The initial sorting through the pack of stimuli was to familiarise Ss with the line drawings without giving them any verbal descriptions of what the stimuli represented as well as to get a rate of sorting which permitted recording the S's response in the experimental trial. When the photograph was presented all Ss recognised it as representing the line drawing on these cards. Most of the Ss had not seen the ambiguous figure before, 10 Ss had, but none had difficulty in perceiving both aspects. On questioning after the experiment the Ss reported that in the initial presentation they had recognised the various cards as a line drawing of a face. The size of stimuli used in this experiment was equivalent to that of Ramamarthi and Parameswaran (1964).

The most significant effect evident from Figure 4. 3 and from the GLIM analysis was that, as hypothesised, the presence of the YE element strongly influenced the tendency to report YW whereas its absence increased the number of OW responses.

This effect was very much more evident than from the afterimage experiments and confirmed the hypothesised effect of this element in a free viewing situation.

The next most effective element was the presence or absence of the M element. No effect was found for altering the size of this element. The presence of either size of mouth increased the number of OW responses and the absence of such an element increased the number of YW responses. The size of this element was, therefore, not important. This supported the hypothesis that it was not the size but rather the interpretation afforded this element which was important. This is evidence against the hypothesised smaller Gestalt area formed by this element to favour a YW response (suggested as an alternative explanation of the results of Experiment 1). This result confirmed the afterimage experiments' results which showed the effectiveness of this element in eliciting the OW response.

The effect of the E/EC element was also significant ($p < .001$), its absence increasing the number of YW responses and its presence decreasing this number. In Experiment 3 when the presence or absence of this element was investigated in an afterimage situation no main effect of this element was found, although, interactions between it and other elements were important. No main effect for the CL element was found, although the interaction between this element and YE element was significant (Figure 4.4). When the YE element was present then CL presence increased the number of young woman responses whereas when the YE element was absent then CL presence increased the number of OW responses.

No main effect of sex was obtained, although the sex x 'young woman's nose' interaction was significant (Figure 4. 4) such that the absence of the YE element produced more OW responses in males than in females.

This experiment demonstrated that in a free viewing situation altering the elements had rather similar results to the afterimage experiments. Presence of the M element which was shown by the previous experiments to increase the proportion of the OW response was confirmed here. As hypothesised the YE element greatly determined whether the stimulus was responded to as the YW aspect. This effect was not so obvious in the afterimage experiment which demonstrates that fixation position is important. That is, if the response is determined by the weightings of the available elements, then this availability will in itself be determined by the fixation position. The fixation positions used in Experiment 3 may have mitigated against the availability of this element for the S.

It is hypothesised, therefore, that in a free viewing situation if the eye movements of the Ss were recorded it is predicted that they would have fixated towards this element when a YW response was given and fixated more towards the M element when responding OW.

The next experiment reported examined the effect of presenting different versions of the line drawing to two groups of children, using a free viewing situation.

4.3. EXPERIMENT 5

4.3.1. Introduction

The previous experiment examined the effect of free viewing on the perception of the ambiguous line drawing when a student population was used. The present experiment extended this to two groups of children of different ages.

Some age-related differences have been reported with ambiguous and reversible perspective stimuli (discussed in section 2.5.3). The interest here was to see if altering the elements of the line drawing had an age-related difference on perception of the figure. Hochberg (1970a) has used the term 'mature observer' to describe the experienced observer who has a vocabulary of schematic maps. It was hypothesised that by using children then altering the elements of this simple stimulus would enable elaboration of how such maps are acquired and developed. If this process was age-related then an older child should have more available to him the two alternative maps for the ambiguous figure. Therefore altering elements ought to have more of an effect upon an older child's response than for a younger child, i.e. the older child should produce results more similar to the previous experiment. A younger child, it was hypothesised, will not have such map availability and so altering the elements would not so readily produce different responses.

Girgus and Hochberg (1970, 1972) have demonstrated age-related changes in the ability to recognise sequentially part-presented geometric forms over an age range of approximately 4 - 10 years. This ability increased with age and was enhanced when the S was allowed to select his own sequence of input of stimulus parts. In these studies the child essentially viewed the stimulus through a small hole. This situation is unlike normal viewing in that the former denies any peripheral vision. The result of this work demonstrated that with age the ability to integrate each 'glance' of the stimulus increased. In

Hochberg's terms this demonstrates easier acquisition with age of the appropriate schematic map.

It was considered here that by presenting children with a large stimulus, typically requiring several 'glances' and associated eye movements to examine it then this would approximate such a sequential presentation technique, except that peripheral information would here be available.

In the large line drawing of the ambiguous figure there are few cues to each aspect (these cues are considered to be the weighted elements) and these cues are spatially distributed. Through emphasising the immediate response to each stimulus as soon as the child saw it then the older child should be better able to integrate the available elements than the younger child and so respond more appropriately. An ambiguous stimulus requires two schematic maps and so it was hypothesised that the older child would be more able to switch maps as the stimulus elements were altered.

A pilot study was first carried out using children of different ages to determine an adequate methodology which would both allow a group of children to be simultaneously tested as well as to determine a response measure suitable for an Analysis of Variance treatment. The pilot study also served to demonstrate that children about 8 years old could adequately respond in the manner described in the following experiment.

4.3.2. Subjects

64 children, all pupils at a local junior school, served as subjects. The children were chosen so as to form two groups with an age of either 8-9 years or 10-11 years with equal numbers of males and females in each age group. The mean age of each group respectively was 8.5 years (S.D. 0.50) and 11 years (S.D. 0.49).

4.3.3. Stimuli

The sixteen stimulus conditions produced by the presence or absence of each of the four pictorial elements were photographed so that 32 prints of size 20.5 cms x 13 cms (horizontally) were made with every condition being printed twice, facing both left and right. These photographs were then attached to a sheet of white paper containing a 10 cms horizontal line extending between the words 'old woman' and 'young woman.' Multiple xerox copies of these were then made. The stimulus drawings subtended some 24^{o} x 16^{o} visual angle at the S's eye. An example of one of these stimuli is shown in Appendix B.

A computer program based on the Fortran random number generating function was used to produce a table of stimulus conditions for each S so that each child received all 16 conditions facing both left and right (total of 32 conditions) in a different randomised order. Within each age group every child received a unique first condition so that the 32 children in an age group first received one of the 32 stimulus conditions. Each subject's 32 stimulus sheets were then stapled together.

Four enlarged prints, two of the full (all 4 features present) ambiguous line drawing and two of the original Boring's ambiguous figure were produced so that each was facing in both directions. The prints were of size 30 cms x 22 cms and mounted on card.

4.3.4. Procedure

The 64 subjects were run in 8 groups of eight similarly aged children. The experiment took place in one day and the children prevented from communicating to those not already examined. All the children were volunteers being previously told by their class teacher that they would be required to play a game involving looking at some pictures.

The group of eight children was seated at school desks in a semicircular fashion around the experimenter who then gave out 8 of the sets of stimuli face down on the desks. The desks were so arranged to prevent any copying between Ss and the experiment was conducted in a small classroom.

Each child had a pen or pencil and was asked to write their name, age, and whether they were a boy or girl on the back sheet of the stimuli set.

The experimenter instructed the children that he was going to show them a photograph and that they had to write down on the back sheet what it was a picture of. He then showed them one of the photographs of Boring's figure. Half the groups of children in each age category were shown the left facing version and half the right facing version. Having done this they were told then to write the letter R or L on the sheet depending on the direction of the face in the photograph. Both photographs of Boring's figure were then held up simultaneously and the Ss told:

> "These are two pictures of the same thing, a picture of a woman's face, in one she is facing left and in the other she is facing right. The pictures themselves are trick pictures. In each one there is not just one woman's face, but two. Can you see both?"

The two aspects were then verbally elaborated as in Experiment 1. When all the children could distinguish both aspects and reported that they could alternate between them then both the line drawing photographs were simultaneously held up and the Ss instructed:

> "These are two outline drawings of the same photograph, again you should be able to see both the young and old woman in them. Can you see them? O.K. now I want you to just look at them for a little while and see if you can change from seeing one to the other. Can you do this?"

The children were then given a few minutes to look at the line drawings and practice alternating between the two aspects. The experimenter then held up an example stimulus sheet.

> "This is a similar picture to the ones I have just shown you. It is somewhat smaller and it also has a line at the bottom running from the words 'young woman' to the words ' old woman.' What you have in front of you is a pile of similar pictures. For each picture I want you to look at it and decide whether you think it looks more like one woman's face or the other and having decided this I want you to put a little vertical mark, like this (demonstrated) on the bottom line. If you think it looks very much like the young woman the mark will be towards the right hand side (demonstrated), if it is very much like the old woman then you will put the mark towards the left hand side (demonstrated). If it looks like both it would be more in the middle and so on. If it looks more like one than the other then it will be towards that side. You can mark anywhere along the line depending on how much you think it looks like one or the other face. Any questions?"

The experimenter then demonstrated this procedure, not actually marking the paper, but illustrating how the mark could be anywhere along the bottom line.

> "The pile of papers in front of you is a lot of pictures similar to this, each with this horizontal line at the bottom. You might think some of the pictures look more like one face than the other. Now when I tell you to. I want you to turn the pile of papers over and look through them at your own speed, deciding whether each picture looks more like one face or the other as soon as you see it and for each one putting a mark on the bottom line just as I demonstrated. Remember there is no hurry, take your time, but try and mark how you see the picture as soon as you see it.

> When you turn the pile over you will notice there is a pink sheet of paper beneath the top picture, this is to help you keep your place. When you have looked at the top picture and decided where to put your mark then turn over to the next picture and place the pink sheet beneath the second picture without looking at the third picture. Do it just like this (the procedure was demonstrated). When you have completed all the pictures just sit quietly until everyone else has finished."

The experimenter then demonstrated what was required of the Ss as he went through the pictures.

When all the Ss were able to readily perceive both aspects in the line drawings and were aware of what was required the experimenter told them to turn the papers over and start. When all Ss had completed the task they were asked to sort through the pictures again, not to change any of their ticks, but to check that they had not missed any of the pictures. The papers were then collected in, the Ss briefly and simply told the purpose of the experiment and instructed not to tell anyone else about it until all the other children had been run.

4.3.5. <u>Results</u>

Each mark on the scale between old and young woman was assigned a numerical value equal to the distance in mm from the old woman end of the scale. Thus 0 = old woman and 100 = a young woman response.

An Analysis of Variance was then performed on this data with two between-Ss factors and five within-Ss factors. Each factor had two levels. The between-Ss factors were:- age of the children (young or old), and the direction of the initial photograph shown to the children (left facing or right facing). The within-Ss factors were:- the presence or absence of each of the four stimulus elements and the direction in which the ambiguous figure was facing. For each age group there were 16 children who were first presented with the ambiguous figure facing in a particular direction. 3 children from each of the four 'age-direction of initial photograph' groups were dropped from this analysis for the following reasons.

In the older age group the six children dropped included one child who failed to mark or else multiply marked 10 conditions, one who multiply marked 6 conditions, two who failed to mark 3 conditions and two who similarly missed 2 and 1 conditions respectively. In the younger age group three children missed 2 conditions, one missed 1 condition and scored all the rest as 0 or 100. The other 2 children dropped to make equal numbers of Ss in each 'age-direction of initial photograph' group were selected as having either simply scored 0 or 100 on more than 25 of the 32 conditions.

The data of the remaining 52 Ss, with 13 Ss in each 'age-initial direction' group, was analysed using the Bwanova statistical program. The full results of this analysis are presented in Appendix C . Figure 4.5 presents the mean values of the effect of each parameter studied. Due to the large number of possible interaction effects it seemed reasonable to adopt a significance level of $p \leq .01$. The effects of the 5 within Ss factors at each age level are shown in Figure 4. 7 . No main effect of age was found. Neither was there any effect of the direction of the initial photograph. Similarly, no main effect was found for whether the stimulus conditions faced right or left. Responses to each stimulus are shown in Figure 4.6 .

The presence or absence of three of the picture elements was significant. For the M and YE elements this was highly so ($p < .001$ in both cases) whereas the E/EC ($p < .01$) was less significant in its effect. Presence of the YE element increased the proportion of the young woman reponse whereas the presence of the other three elements increased the amount of old woman responses. Presence of the CL element also increased the proportion of OW responses although not sufficiently for the result to be significant at the selected probability level. None of the interaction effects were significant at this

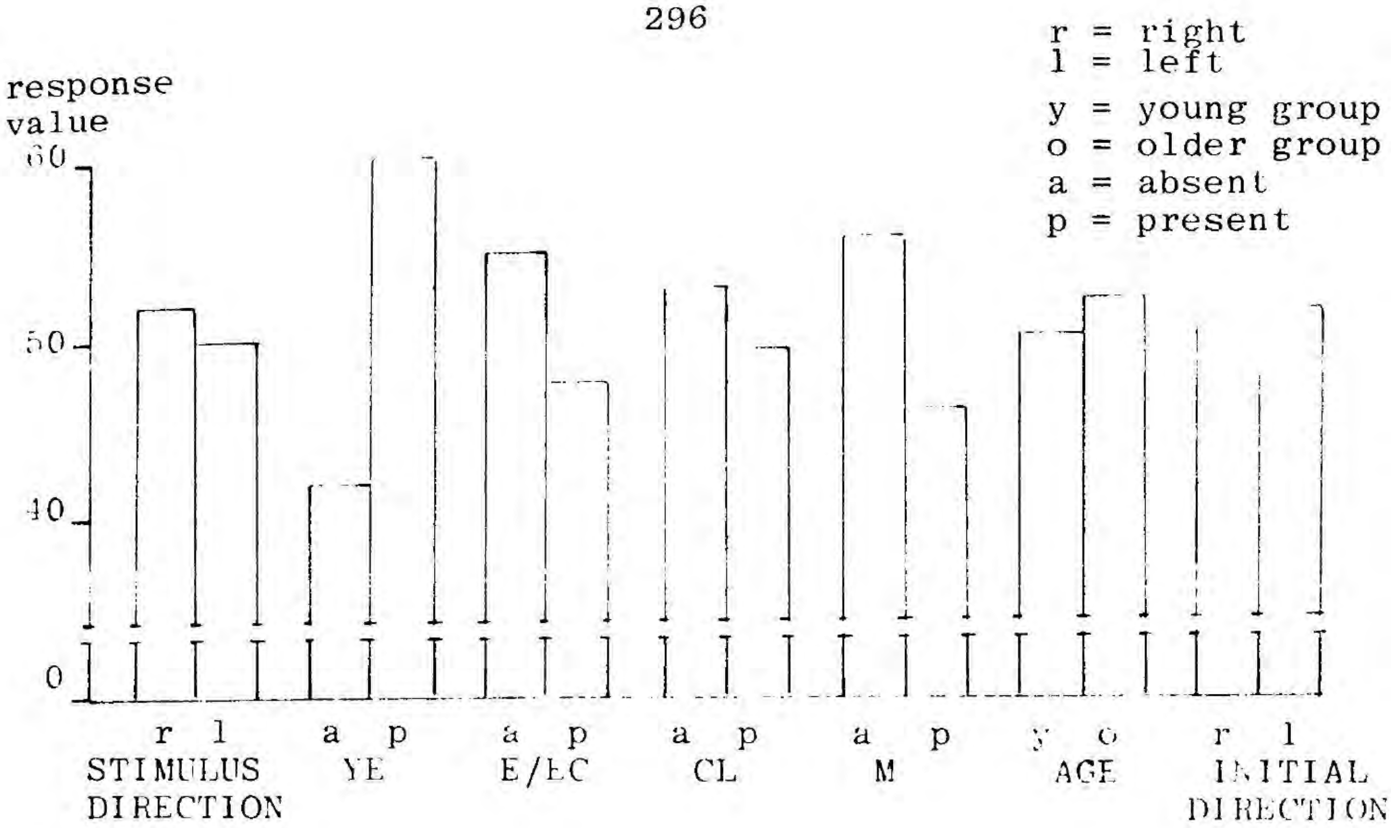


Figure 4.5 Mean values obtained for each experimental parameter.

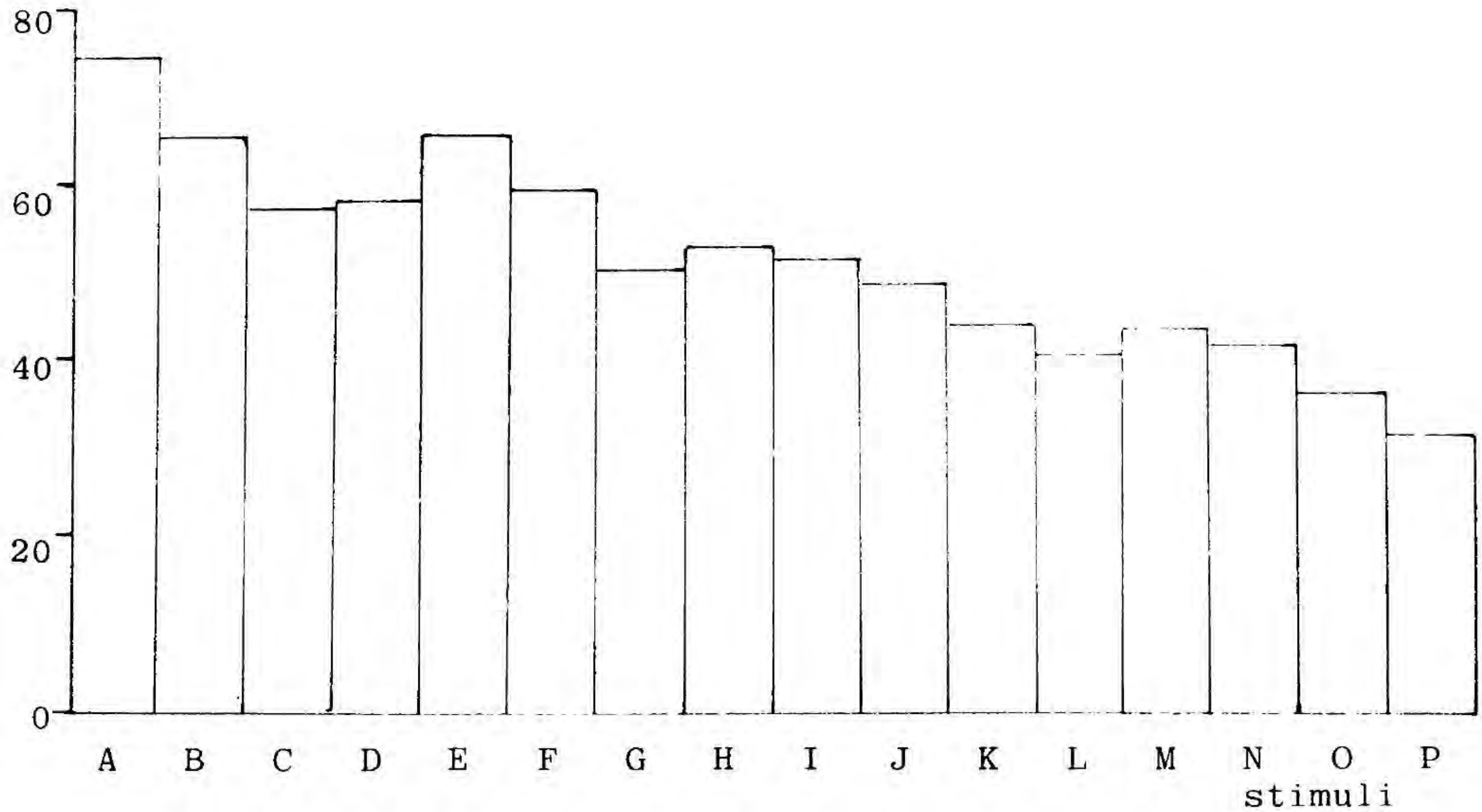
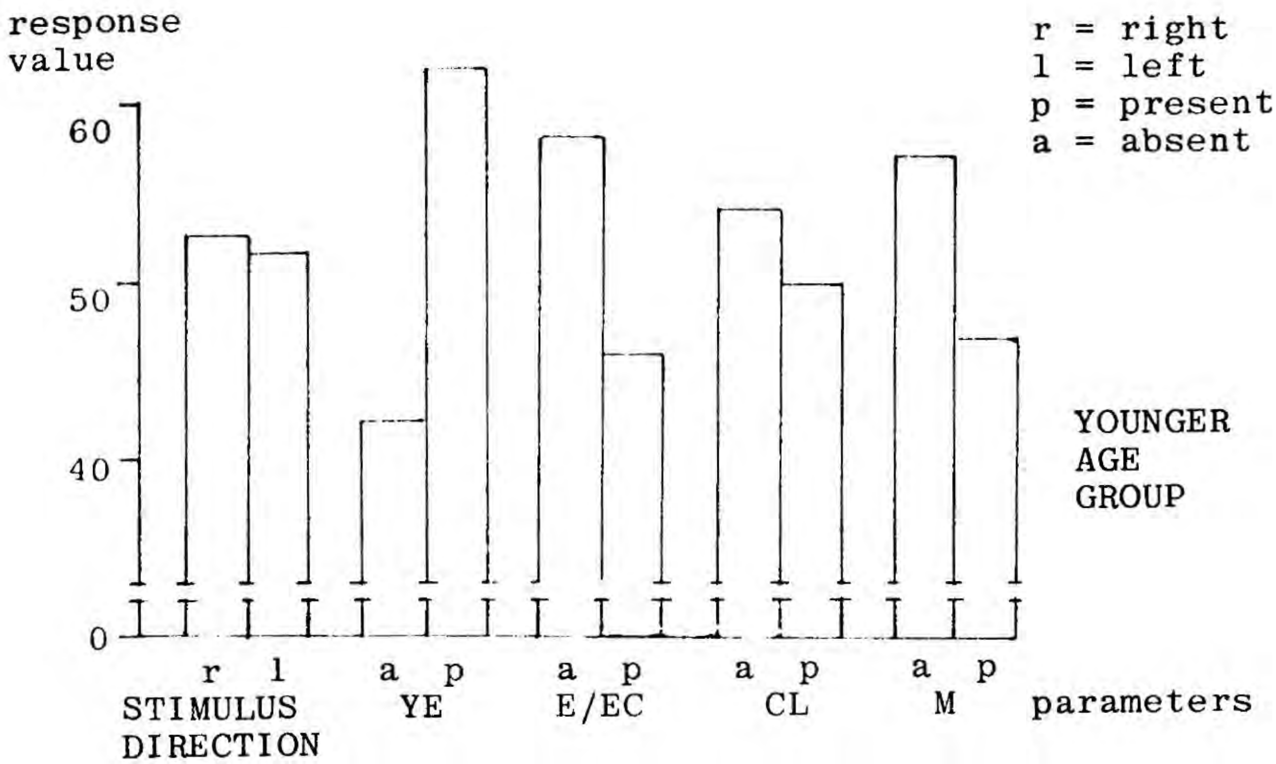
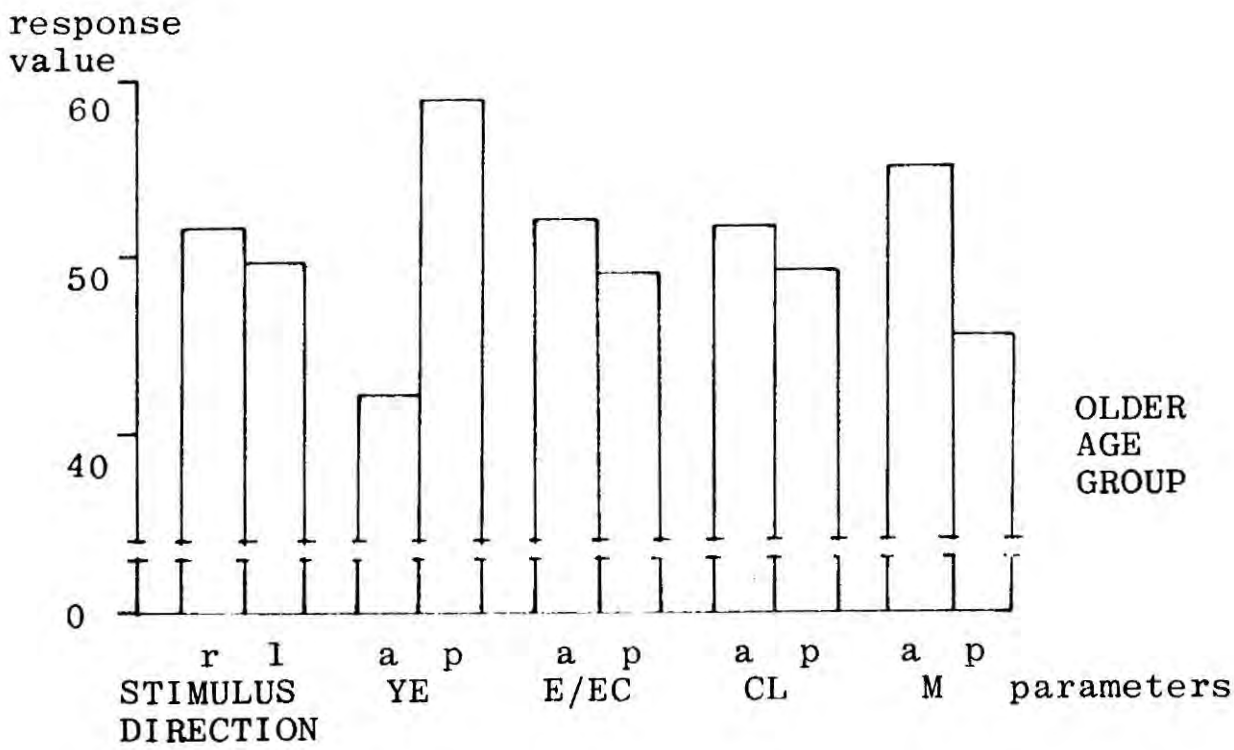


Figure 4.6 Mean response values obtained for each of the 16 stimulus conditions.





<u>Figure 4.7</u> Mean response values obtained by each age group for the presence and absence of the 4 elements and the stimulus direction.

selected level either.

4.3.6. Discussion

This study again confirmed the effect of the presence or absence of the four determined elements in the line drawing of Boring's figure. The effect of these elements was similar to the previous experiment in which students were used. Again the effect of the YE element in eliciting a response of YW was much more than was found in the previous afterimage studies. The effect of the M element in producing an OW response was again very evident. As in the previous experiment a significant effect of the E/EC in aiding OW perception was confirmed. In the afterimage experiment where this element was altered significant interaction effects between this and other elements were found. The two experiments presented in this chapter may not be directly comparable however, due to the different sizes of stimuli and designs used.

The most interesting finding in the present experiment is that there was no significant difference between the two age groups in terms of their responses to the stimuli. The two age groups (8.5 and 11 years) were selected for two reasons. Firstly in this design the child must have a grasp of what is required as regards the response technique. This tended to set a minimum useful age as determined by the pilot study. The upper age limit was that of the oldest age group of children in the school.

Secondly, some previous work has suggested that this age range would produce different responses. Holt and Matson (1976) reported that age related effects were most significant in children between 5-10 years using the Necker cube. Bartol and Pielstick (1972) examined stimulus preference using various ambiguous figures and concluded that preference for ambiguity increased with age.

The failure to find age-related differences in the perception of the ambiguous figure used here demonstrates that both age groups utilised the same cues or elements in determining the response of figure. What the study does not elaborate is whether age-related differences occur in the way such elements are integrated. From Figure 4.7 the older age group tended to respond more as the young woman than did the younger group when the stimulus conditions were such as to elicit this aspect. This is in accord with the hypothesis that the younger children would not so readily respond to such stimulus manipulations as the older group although this difference was not significant.

The integration of the elements may be reflected in different eye movement parameters. For instance, age related differences in eye movement distributions have been proposed by various theorists (e.g. Piaget, 1969; Hebb, 1949), where the younger child is proposed to make more eye movements. Such differences may reflect, in Hochberg's terminology, the way in which a schematic map is organised. Some age differences in eye movement patterns have been reported (Whiteside, 1974; Mackworth and Bruner, 1970). However, no such age-related differences in eye movements were found by Girgus (1976) in an aperture viewing situation in which age differences were found for the accuracy of shape perception.

Other experiments would need to further investigate the manner in which the elements of the ambiguous figure are integrated by different aged children, whether this is in terms of eye movement patterns or not needs to be established. This is a topic for future research which was not pursued here as such possible age effects were not the prime research interest.

4.4. SUMMARY

Two experiments are reported using both students and children which demonstrated that the effect of the elements found in the previous afterimage experiments were further elaborated in free viewing situations. This occurred for all ages of subjects used, demonstrating the generality of the effect of particular elements. The influence of the YE element in eliciting the YW response was greatly enhanced in these studies compared to the afterimage experiments. The effect of the M element in causing a response of OW was further confirmed.

In these two experiments large stimuli were used with no control of fixation position and the S's immediate response to the stimulus was emphasised. In these conditions, finding the same effects of elements as in the afterimage studies where fixation was controlled confirms the role played by para-foveal processes in eliciting the response of one or other of the possible aspects.

It is hypothesised that if eye movements were recorded in such free viewing situations then a S's fixation location would be in accord with an area of the stimulus in which the element or elements were weighted towards the aspect the S was currently reporting.

In the following chapters suitable apparatus for recording such eye movements is first described followed by an experiment in which this is investigated.

C H A P T E R 5

THE EYE MOVEMENT RECORDING TECHNIQUE

5.1. INTRODUCTION

The previous two chapters have described experiments with the ambiguous figure in which fixation position was controlled, in combination with an afterimage technique, and also where a free viewing situation was employed. Information has been gained from these studies as regards the use made of the elements of the ambiguous figure together with the effect of fixation position. The next step was to record the eye movements of Ss as they viewed the figure and reported fluctuations. Before this could be done a suitable recording method of such eye movements had to be devised.

In this chapter the development of a technique is described which would measure the eye movements of Ss as they view the ambiguous figure. The criteria of such a method were outlined in section 2.3.4.: namely, the recording should be unnoticed by the S and the accuracy should be about 1^{o} visual angle.

The various types of eye movements are first described and the particular kind of movement occurring in viewing pictures elaborated. The different techniques used to record eye movements are then detailed. These are then evaluated and the choice of a suitable method is made and then fully elaborated.

The apparatus built to record the eye movements is first detailed and then the two techniques developed to score the video recording of the eye movements described. The sources of error in this method of eye movement recording are next considered and the procedure for correcting these errors discussed. An evaluation trial of the technique is then detailed together with an outline of the computer programs which were written to fully analyse and plot out the eye movement data.

5.2. THE TYPES OF EYE MOVEMENTS

Movements of the eyes can reliably be classified into the following categories. Each kind of movement has its own peculiarities which distinguishes it from the others.

5.2.1. Saccadic Movements

These are typically rapid conjugate movements, under voluntary control, which are ballistic in nature. Although Weber and Daroff (1971) have reported dysconjugate horizontal saccades. The purpose of these eye movements appears to be to bring regions of interest to fall upon the small foveal area of the retina. The majority of saccades are less than 15^{o} in amplitude (Lancaster, 1941).

Saccades often overshoot (Thomas, 1961) or undershoot (Yarbus, 1967) their target, thus giving rise to small corrective saccades (Ginsborg, 1953).

Robinson (1964) found that temporal saccades produced more overshoot than nasal ones. Fuchs (1971) has pointed out that if a fixated target steps greater than 20^{o} then the saccade elicited undershoots by almost 10% of the final position. Undershooting of the final target position as the saccade amplitude increases has also been reported by Weber and Daroff (1971).

The duration of the saccade depends upon the magnitude of movement. For movements over 5^{o} amplitude (Dodge and Cline, 1901) the duration is approximately 20-30 ms plus 2ms per additional degree (Robinson, 1964) and is not under voluntary control (Yarbus, 1967). Saccades have very high initial acceleration and deceleration (up to $40,000^{o} s^{-2}$ varying with the saccadic amplitude (Yarbus, 1967) with a peak velocity of up to $700^{o}s^{-1}$ (Carpenter, 1977) for large amplitudes. Yarbus (1967) gives the figure of $450^{o}s^{-1}$ for a 20^{o} saccade. A refractory period exists between saccades of about 150ms and they have a latency of 100-300ms in response to a visual step stimulus which varies with the saccadic jump (Saslow, 1967; Bartz, 1962). Oblique saccades may be curved (Yarbus, 1967).

Vision is not completely eliminated during saccades. The visual threshold is elevated just prior to and during a saccade, this being called saccadic suppression (Volkmann, 1962; Zuber and Stärk, 1966).

5.2.2. Pursuit Eye Movements

These are conjugate movements which track slow moving objects in the visual field and typically require a moving object to elicit this type of movement (Yarbus, 1967). They are not usually under voluntary control (Robinson, 1965).

They function to partly stabilise on the retina objects moving within the range $1\text{-}30^{\circ}.s^{-1}$. They have a latency of about 0.2s (Shackel 1967; Yarbus, 1967). Pursuit movements have been neurologically distinguished from saccades by several workers (e.g. Rashbass, 1960). Alpern (1969) has pointed out that the stimulus for a pursuit movement is largely a velocity error whereas that for a saccade is a position error. Rashbass (1960) having earlier demonstrated that target velocity and not target position was the main stimulus for a pursuit movement.

Smooth eye movements, similar to pursuit movements can also be made in the absence of a moving visual stimulus. The eliciting technique involves tracking an afterimage (Heywood and Churcher, 1971, 1972). Heywood (1972) has also reported a case of a subject who could both voluntarily execute and apparently control such smooth movements in the dark. Such subjects appear to be rare, Richards and Steinbach (1972) reporting another case.

5.2.3. Compensatory Eye Movements

These are smooth compensatory movements which are related to pursuit movements and act to compensate for movement of the head or body so as to partially stabilise an object upon the retina during such motion. Like pursuit movements they can compensate for a movement rate of 1-30^{o}.s^{-1} (Miller, 1958) and have a latency of 0.03 to 0.1s for passive body movements.

5.2.4. Miniature Eye Movements

When a S voluntarily fixates on a target the eye is still subject to several types of motion all generally less than 1^{o} in amplitude. These include flicks, drift, irregular movements and high frequency tremors (Ditchburn and Ginsborg, 1953). The effect of these movements is to irregularly shift the retinal image about the retina over an area which is larger than the foveal receptors (Carpenter , 1977), thus preventing the image of the object from fading (Fuchs, 1971).

Flicks are miniature saccades, also called microsaccades, which usually reposition the eye on the target (Steinman,Haddad,Skavenski,and Wyman(1973). They are predominantly corrective movements, correcting the off-centre foveal position produced by the drift movement. The likelihood of their occurrence increases with the distance between the foveal centre and the fixated target (Cornsweet, 1956). They may also serve a similar visual search function to that of the large saccadic eye movements (Steinman, Cunitz, Timberlake and Herman, 1967; Haddad and Steinman, 1973). They have a range of 1-20' (Alpern, 1969) but can be as large as 1^{o} (Young and Sheena, 1975b)having an angular velocity of some $10^{o}.s^{-1}$ and occurring at irregular intervals. The close relationship between the behaviour of microsaccades to that of gross saccades has been demonstrated by Ginsborg (1953) and also Zuber, Stark and Cook (1965).

Drifts are slow movements of approximately 5' amplitude away from a fixation point having an angular velocity of about $1'.s^{-1}$ (Ratliff and Riggs 1950 ; Ditchburn, 1973). Nachmias (1959) reports that in any individual both drifts and flicks occur along a preferred axis.

An irregular slow motion of the eye which differs both between and within Ss, having a frequency of 2-5 Hz and amplitude of 1-5' has been described by Ratliff and Riggs (1950).

High frequency tremor has a frequency of 10-150 Hz (Carpenter, 1977). The amplitude is of the order of the smallest cones (24") of the eye. Tremor is apparently uncorrelated between both eyes (Riggs and Ratliff, 1951) and causes the image of a fixated point to describe a conical surface on the retina (Yarbus, 1967).

5.2.5. Vergence Eye Movements

These permit acquisition of near or far objects by means of the eyes moving in opposite directions so as to provide adequate binocular fusion of the two images of an object (Zuber, 1971). Both binocular disparity and focussing errors can give rise to such movements, as can accommodation (Carpenter, 1977; Westheimer, 1971). These movements are slow (Dodge, 1903) with a latency of about 160 ms in response to a sudden step change - being less for convergent movements than for divergent movements (Yarbus, 1967) with Robinson (1965) giving the figure for vergence rate of $10^{o}.s^{-1}$ for each degree of inter-retinal error.

5.2.6. Nystagmus

Rhythmic constant shifting of the eye consisting of an alternating slow and fast phase is known as nystagmus. Several types of nystagmus exist. Optokinetic Nystagmus is produced by moving repetitive patterns in the visual field (Walls, 1962). Rather similar is Vestibular Nystagmus caused by stimulating the semicircular canals as the head is rotated. Voluntary Nystagmus is a pendular movement found in some individuals. Both phases have similar velocity unlike Optokinetic and Vestibular Nystagmus.

Latent Nystagmus is a rare clinical condition in which no nystagmus is present when binocular vision is permitted, but occurs when one eye is occluded (Alpern, 1969).

5.3. EYE MOVEMENTS IN PICTURE PERCEPTION

In the research presented here the eye movements of interest are those of a S searching a static pictorial display. In this situation the predominant type of eye movement is the saccade. The perception of such a stimulus being considered as an alternating sequence of saccades and fixations. Although miniature eye movements will be present in the fixations they are of minor concern here. At least two major works on eye movements during picture perception have been published (Buswell, 1935; Yarbus, 1967) and is a topic of much research (e.g. Gould, 1976). This is dealt with in the next chapter.

5.4. EYE MOVEMENT RECORDING METHODS

There exist several possible techniques for recording eye movements. Each approach has its own advantages and disadvantages, being appropriate for particular cases. Several full or partial reviews of these methods have appeared (Glen, 1940; Lord and

Wright, 1950; Russo, 1975; Monty and Senders, 1976; Young 1963; Young, 1970; Young and Sheena, 1975a, b). The following section considers each approach in turn and then evaluates them for the present purposes selecting the most appropriate technique.

5.4.1. Direct Viewing

Yarbus (1967) reports that with practice one can detect movements of about 1^{o} amplitude by simple direct observation. This approach has no long term usefulness as no record of movements is made. However, it has found favour with the recording of lateral eye movements in response to particular question types. Here the experimenter is interested in both the occurrence of a horizontal movement and its direction at particular times during an experiment, no measure of the extent of movement being required. A bright spot (blob of mercury) attached to the eye can be a useful aid in detecting movements in this way (Barlow, 1952).

5.4.2. Contact Lens

A contact lens attached to the eye can be used to measure eye movements either electromagnetically or optically. With the latter system collimated light directed towards the eye is reflected from a mirror attached to the contact lens, the mirror acting as an optical lever (Orschansky, 1898). The mirror is usually mounted on a stalk attached to the lens. Rotation of the eye alters the angle of reflection of this light which is detected by a suitable photocell to give a measure of eye movement. Other detectors have been used, e.g. Ditchburn and Ginsborg (1953) utilised film recording. Haddad and Steinman (1973) have used such a mirror system in conjunction with an attenuated laser as the light source. Small lateral head movements do not affect this reflection as long as the head is quite well stabilised with respect to the recording apparatus (Ratliff and Riggs, 1950). More than one mirror has been mounted on the contact lens. Matin and Pearce (1964) used 2 mirrors which enabled torsional movements to be recorded as well as vertical and horizontal ones. Fender (1964) has also used multiple mirrors.

An alternative to the optical lever is the use of a multiple line pattern attached to the contact lens (Forgacs, Jarfas and Kun, 1973) which when imaged through a slit onto a moving film has been successfully used to measure vertical, horizontal and torsional movements.

Electro-magnetic detection of eye movements is accomplished by using implanted coils in the contact lens. The coils are mounted at right angles to each other and the S sits in a uniform, alternating magnetic field induced by other larger coils placed about the S's position. When the eye rotates small voltages are induced in the implanted coils which give a measure of eye movement (Robinson, 1963). Eye rotation is recorded without translational effects. Collewijn, Mark and Jansen (1975) have used this technique but with a scleral ring instead of a contact lens.

High resolutions are reported for contact lens techniques, e.g. 2-3" of arc (Matin and Pearce, 1964) with Robinson (1963) reporting 15" of arc for his technique. The optical level systems are restricted to small movements ($\mp$ 5^{o}) of the eye as the inertia of the device affects accurate recording of larger saccades. The main difficulty of both approaches is that of contact lens slippage which can be interpreted as an eye movement (Barlow, 1963) and which is important when such high resolution is required. Fender (1964) reports lens slippage of 1 min. of arc during a 1^{o} saccade.

Different techniques of attaching the contact lens to the eye have been employed. Some of these increase the negative pressure between the lens and the cornea to prevent lens slippage.

Yarbus (1967) used a suction device. Fender (1964) implemented the use of a solution of sodium bicarbonate between the eye and the lens, this caused osmotic action which reduced the pressure under the lens. These methods involve the use of an anaesthetic as they are painful to the S. The mirror can be attached to the contact lens by a stalk in which case blinking by the S becomes a problem. When the alternative of attaching the mirror directly to the contact lens is used then the light reflected can be affected by the tear film of the eye: Nayrac, Milbled, Parqet, Leclercq and Dhedin (1969) have used a small radiating source on the contact lens and monitored vertical and horizontal eye movements with two photomultipliers. This permitted blinking and was useful over a range of .3 to 30^o having a resolution of 20' of arc.

5.4.3. Limbus Technique

The boundary between the coloured iris and the white sclera of the eye is known as the limbus. Each side of this boundary is differentially reflective of incident light. Several techniques use this fact as the basis of recording eye movements.

Given that some suitable detector is measuring the amount of reflected light from an area of the eye which incorporates this limbus boundary, then the amount reflected will increase as more and more sclera is present in the sensed area. Reflection from the iris area is dependent upon the iris colour and the wavelength of the incident light, being less than for the sclera. If the device is measuring horizontal eye movements then movement one way will increase the scleral reflection whilst movement in the opposite direction will decrease it. Similarly, if the sensed area is appropriately located then vertical movements will also increase or decrease the scleral reflection. A typical device uses a light source (often infra-red) and photocells mounted on a spectacle frame.

Torok,Guillemin and Barnothy (1951) were the first to use this principle by imaging a horizontal slit of the eye upon a photomultiplier. Richter (1956) used diffuse reflected light and recorded horizontal and vertical movements independently. The S wore goggles, which contained both the light source and detector. A visible light source with a removable infra-red filter has also been employed which permits easy visual alignment on the limbus prior to infra-red recording (Gaarder, Silverman, Pfefferbaum, Pfefferbaum and King, 1967).

The technique is quite accurate, better than 0.5^{o} over 30^{o} horizontally and 20^{o} vertically (Russo, 1975). Young and Sheena (1975b)quoting a higher accuracy of 15-30' of arc when a spectacle frame is used containing the detector, although Young (1970) gives a figure of 1^{o} accuracy for vertical movements for his own device. Changes in ambient illumination can cause problems as this will possibly be detected and taken as a movement of the eye. This is overcome by 'chopping' the light source (Wheeless, Boynton and Cohen, 1966) or using infra-red light emitting diodes (Young, 1970) and demodulating the detected output changes of the detector photocells.

With limbus techniques vertical eye movement measurement is difficult due to movements of the eyelids which can also affect the amount of reflected light if they enter the detected area. Careful selection of such areas overcomes this or the eyelid movement itself can be used, this being closely related to vertical eye movement (McEwen and Goodner, 1969). The vertical movement of the upper eyelid was employed by Young (1970) whereas Mitrani, Yakimoff and Mateef (1972) tracked the lower eyelid.

Various arrangements of source and detectors have been employed to obtain the best performances from each system. The areas sensed on the surface of the eye having to be chosen so that eye movements within the measurable range will affect the detector output (i.e. the limbus boundary remains within the detected area) without causing cross-talk between the two recording areas so that the two separate outputs are no longer independent (Russo, 1975). Jones (1973) used a single incident light source with two short focal length lenses mounted in front of the recording photocells such that two rectangular areas of the eye inclined at 90° to each other and 45^{o} to the horizontal were sensed. Wheeless, Boynton and Cohen (1966) also used masked sensing of the reflected light whereas Stark, Vossius and Young (1962) used 2 light sources and 2 photocells sensing small unmasked areas either side of the iris to detect horizontal movement.

Detection of a horizontal slit area of the eye has been used. Wilkinson (1975) recorded horizontal eye movements by using light emitting diodes to illuminate the eye using a lens to image a single horizontal slit on a photodetector. Gaarder, Silverman, Pfefferbaum, Pfefferbaum and King (1967) also employed a single horizontal slit area of the eye reporting the ability to detect movements of 1' of arc within a range of 20^{o}.

Craske and Smith (1975) used four modulated infra-red sources and four detectors placed so as to form the corners of a square around the iris. Resolution of 5' of arc within a 15^{o} x 15^{o} area was possible. Gauthier and Volle (1975) also used four similarly positioned detectors, but only a single infra-red source, with a range of 40^{o} horizontally and 20^{o} vertically, resolution being 1' of arc. Bifurcated fibre optics (Findlay, 1974) have been used to achieve a small sensed area of the eye producing high resolution.

5.4.4. Electro-Oculography (EOG)

The eye essentially contains an electrostatic dipole caused by the potential difference between the cornea and the retina. The higher metabolic rate of the retina ensuring that the cornea is some 0.4 to 1.0 µV positive with respect to the negative electrical pole lying approximately at the optic disk. Skin electrodes placed around the eye can detect the movement of this dipole which moves as the eye rotates (Schott, 1922; Meyers, 1929). This technique is know as electro-oculography (Marg, 1951; Monnier and Hufschmidt, 1951). Horizontal eye movements are detected by electrodes placed at the outer canthi and vertical movements by electrodes placed above and below the eye. An additional ground electrode is located either on the ear or the central forehead.

Both a.c. and d.c. recording techniques are used. Eye position information is given by using d.c. recording employing silver-silver chloride skin electrodes which do not polarise easily. The recording of both vertical and horizontal movements is complicated by possible cross coupling between the two axes as well as non-linearity of the recording. Shackel (1967) reports trial and error attempts to minimize such cross talk. A technique for overcoming this has been used by Jeannerod, Gerin and Rougier (1966) which included recording the vertical movements of both eyes using two superior and two inferior electrodes with the outputs of each superior or inferior pair connected together. Bles and Kapteyn (1973) have also used the same four electrode positions but combine the outputs differently to achieve similar cross talk elimination.

The alternative technique of a.c. recording is used for measuring nystagmus and eye movements where position information is not required.

Young and Sheena (1975b) give the measurement range as $\mp$ 50^{o} vertically and $\mp$ 50 - 80^{o} horizontally. Shackel (1967) reports that 95% of all eye fixations, in the range of 0^{o} to 30^{o} either side of centre, was recorded with an error not worse than $\mp$ 1.35^{o}. This figure represents the separate recording of each axis. Simultaneous recording of both axes possibly leads to a radial error of 1.9^{o} (Shackel, 1967). The response linearity of the technique decreases above 30^{o} movement. Colegate and Hoffman (1974) have reported detection of eye movements of 1-1.5^{0} visual angle by averaging the EOG although when Ohtani, Kuchinomachi and Yagi (1974) constructed a device for detecting saccades using EOG recording they found that the resolution was limited to 2^{o} as greater sensitivity resulted in triggering of the detector by alpha waves or other electrical noise.

Such EOG recording is subject to several problems. The EOG potentials are very small, some 15-200 µV, thus brain potentials (EEG) can be picked up as well by the electrodes. Shackel (1967) has argued that muscle potential 'noise'(EMG) can be eliminated by suitable electronic filtering of the recorded signal and that EEG interference is relatively small being equivalent to an eye movement of some 0.25 - 0.5^{o} visual angle. EEG interference is problematic where rapid eye movements (REM) are recorded during sleep, although common mode rejection techniques (Hord, 1975) can overcome this.

A common artefact in EOG recording is the blink, having an amplitude of 0.5 - 1 µV (Shackel 1967). Some investigators specifically use EOG to record blinking (e.g. Poulton and Gregory, 1952). Variations can occur in the potential difference between the retina and the cornea due to light adaptation (Kris, 1958; Kolder, 1959) as well as diurnal variations (Davis and Shackel, 1960; Gonshoor and Malcolm, 1971). Drift of the EOG due to skin polarisation can be minimised by skin abrasion prior to electrode placement (Shackel, 1967) although this is not suitable for some cases such as newborn infants (Harper, Hoppenbrouwers and Ross, 1976).

The technique does not of itself record head movements thus for accurate eye location upon a stimulus either a separate head movement detector is required or else the head has to be immobilised. Carpenter (1977) comments upon the technique by pointing out that the exact origin of the corneo-retinal potential is unknown and this fact thus poses a major difficulty in basing the measurement technique upon it. For instance, EOG-like recordings have been reported from an enucleated subject (Lippold and Shaw, 1971) which was obviously not produced by a corneo-retinal potential. Byford (1963) recorded eye movements with EOG and contact lenses finding that the EOG recording did not faithfully reflect the eye movements.

5.4.5. Corneal Reflection Methods

Incident light on the eye results in a virtual image, a corneal reflex, of the light source produced by the cornea which can be considered to approximate a convex mirror over its central 25° region. As the eye rotates this image also moves in the same direction relative to the head but only by an amount about half the eye movement itself and so appears displaced in the opposite direction to the actual movement relative to the optic axis of the eye. This occurs because the radius of curvature of the cornea is less than that of the eye itself. Corneal reflection methods are affected by variations in the shape of the cornea, corneal astigmatism and the thickness of the tear film. These factors limit the accuracy of this approach to about 0.5 - 1^{o} (Young and Sheena, 1975b).

The corneal reflex can be recorded in two ways, either alone or in relation to some other eye parameter which is typically the pupil centre. These two approaches are considered here as corneal reflex and point of regard systems respectively.

5.4.6. Corneal Reflex

The eye does not rotate about a fixed centre, thus eye rotation results in both rotation and translation. The latter is greatly enhanced if head movements with respect to the source and recording medium are permitted. A 1mm change in head position being equivalent to more than 12^{o} eye rotation (Ditchburn and Ginsborg, 1953). Stabilisation of the head to the apparatus is thus necessary by either firmly restricting the head or by using the apparatus in a head-mounted fashion.

Dodge and Cline (1901) first recorded the corneal reflex with a photographic plate. The use of movie-film was soon introduced. Buswell (1935) and also Jasper and Walker (1931) used two films, one for horizontal and one for vertical eye movement recording. Miles and Shen (1925) recorded both on the one film. Movements of both eyes were recorded by Clark (1934). Brandt (1937) eventually accomplished recording both vertical and horizontal movements with a 35mm camera. A modified opthalmograph for such recording has also been described by Allen (1955).

Mackworth and Mackworth (1958) reported a system employing closed circuit television recording of a S's eye movements. The S sat with his head rigidly restrained by a bite bar incorporating a dental impression as well as a rear head-rest and cheek-bone supports. With the S in position the television camera was set to record the corneal reflex from the S's right eye of a single, bright light source. The S looked at a television monitor which displayed the stimulus. A television mixer allowed the corneal reflex to be displayed superimposed over the stimulus for the experimenter to study, as well as being recorded on 16mm film for subsequent analysis. Non-linearity of the movement of the reflex was accounted for to some extent by adjusting the S's monitor controls or by angling this monitor with respect to the S. Altering the magnification of the corneal reflex camera was also necessary for different Ss so as to achieve adequate superimposition of the reflex on the stimulus display and was done with the S fixating a calibration stimulus. A later modification (Mackworth, 1967) employed optical superimposition of the reflex upon the stimulus for recording purposes with an accuracy of ∓ 1^o over a 20^o range.

A head-mounted eye movement recorder was developed by Mackworth and Thomas (1962). A helmet arrangement carried an 8mm recording camera as well as the necessary optics. The corneal reflex of a small light bulb suspended from the helmet was picked up and optically mixed by a beam splitter with the scene being viewed prior to recording. An accuracy of ∓ 1^o horizontally and ∓ 2^o vertically being possible. Initial alignment of the reflex over a calibration stimulus was achieved by the experimenter directly viewing the combined optical output of the device.

A commercial instrument is now available (NAC Eyemark) which uses fibre optics so that the camera does not have to be head mounted. The weight of the device for the S is thus reduced. Modifications of this device have been reported which increase the stabilisation of the system on the S's head (Cox, 1973; Gale, Johnson and Worthington, 1978).

5.4.7. Point of Regard

The simple recording of a single corneal reflex is affected by eye translation as well as eye rotation. Corneal reflex methods seek to reduce translation errors by restricting the S's head motion with respect to the apparatus. An alternative technique of overcoming such errors is to record the pupil centre as well as some suitable corneal reflection. Cowey (1963) has shown that translational head movements of some 0.5^{o} do not affect the accuracy of this method. The relationship between the centre of the pupil and some corneal reflection is very nearly constant for a lateral head movement, but changes for an eye movement.

Two approaches have been used with either multiple light sources or a single source.

Multiple light sources. Cowey (1963) developed a method of perimetry for use with monkeys reporting experimental trials with humans where the S viewed points on a perimeter through a peephole. Four photoflood lights directed towards the peephole provided corneal reflections as well as illuminating the S's eye. The recording camera was positioned almost directly in front of the S's position. Cowey demonstrated that lateral head movements of some 1.27 cms did not affect the ability to detect the S's fixation position on a stimulus matrix composed of targets separated from one another by 5^{o} visual angle.

A similar idea of using separate light sources was used by Salapatek and Kessen (1966) and also Haith (1969) for human infants. The use of infra-red light sources aided S eye comfort and in conjunction with a suitable infra-red sensitive film or television camera permitted undetected monitoring. In a similar fashion to Cowey, the camera was placed directly in front of the S hidden behind the stimulus. Slater (1974) also reports a similar system.

The wide angle reflection eye camera (Mackworth, 1968) employed the S viewing a stimulus through a half silvered mirror. Illuminated scales around the edge of the stimulus scene served as the sources to provide the corneal reflections which were recorded by a camera via the mirror. The record displays the S's eye as well as the reflection of the scales. The point of the stimulus being fixated by the S is read off the display by ascertaining the pupil centre and reading this off the scales which are present as the corneal reflections. An accuracy of 1.9° visual angle is reported by Mackworth with this method using a 29.5° stimulus display 38 cms distant from the S.

<u>Single light source - (Oculometer).</u> The oculometer approach uses a single light source effectively placed at optical infinity and which is coaxially aligned with the recording system by a beam splitter. This arrangement ensures that the corneal reflection lies along the axis joining the corneal centre of curvature and the oculometer.

The measured displacement between the centre of the pupil and corneal reflection is thus a function of eye rotation only. The oculometer apparatus containing both the light source and recording apparatus is situated a few feet away from the S.

The technique has an accuracy of about 1^{o} over a wide range; $\mp 30^{o}$ horizontally, $+ 30^{o}$ and $- 10^{o}$ vertically. The vertical measurement is with reference to a line joining the oculometer to the eye. The technique was first demonstrated by Merchant (1968). Subsequently several modifications have been reported e.g. Merchant, Morrissette and Porterfield (1974).

The oculometer approach permits small head movements within a 2.5cc region of space after which the eye is lost. The permitted range of head movements can be extended to some 30.5cc by servo-controlled tracking mirrors in the final common path of the incident and reflected light. Besides the advantage of such free head movement the device is usually completely remote from the S and can be operated without S's awareness. A helmet mounted version of the oculometer has also been devised (Merchant, 1974).

Originally an image dissecter was used for recording the eye movements, but subsequent systems exclusively use video recording. In this format the data is very amenable to on-line analysis which can also be used to control the servo-controlled mirrors. By limiting the incident light to the infra-red region the S is relatively unaware of its presence and due to the coaxial arrangement the incident light reflected and scattered back from the retina serves to backlight the pupil. This aids electronic processing as the problem is then one of tracking the bright corneal reflex in relationship to the centre of the less bright disc of the backlighted pupil (the so called 'bright pupil'). Visual and electronic filtering can then remove all the rest of the eye detail to aid this processing.

A similar system has been detailed by Albutt, Bamborough, Churcher, Heywood, Rice and Salter (1975) which does not use servo-controlled mirrors and has a resolution of 1^{o} horizontally and 1.5^{o} vertically. Davis, Lutz, Warner and Iannini (1971) constructed a portable oculometer with a resolution of 1^{o} over some $\mp 20^{o}$ vertically and horizontally. More recently Middleton, Hurt, Wise and Holt (1977) report an updated version for recording pilot's eye movements. Merchant (1977) has provided a recent summary of developments in this field.

Some systems do not utilise the bright pupil technique, relying instead on the conventional 'black' pupil. Lambert, Monty and Hall (1974) use this approach (also reported by Monty, 1975). In this system the S views stimuli on a screen which is surrounded by polarised light panels. These provide a background light level. A small section of this panel is unpolarised and this acts as the light source. A concealed television camera records the movements of the corneal reflex of this source and one of the S's eyes within 30 cms of space via feedback controlled mirrors. For analysis purposes an operator first superimposes a cursor on the pupil and this is then automatically tracked by a digital computer until the eye is lost (e.g. by blinking) when the pupil has to be manually realigned with the cursor again.

Sheena (1973) has developed an oculometer which also uses a 'black' pupil. Here delimiters are first applied by software both to the edges of the corneal reflection and the pupil in the television picture, prior to estimating the S's point of regard.

The use of on-line digital analysis permits allowance for calibration and non-linearities can be accounted for by suitable software. The disadvantages of this is in terms of the very high capital expenditure needed for the purchase of a commercial system. The basic oculometer principle is quite simple, however, and a system can be built on a small budget which permits a small range of head movements by using a smaller image of the S's eye together with manual analysis of the video-taped eye movement recording. Such a system has been described by Gale (1979) for use in an industrial inspection situation.

Both types of point of regard systems can give pupil diameter as an output in addition to eye movement information. This is particularly the case where automated analysis, as in the oculometer, is utilised.

5.4.8. Ellipticity of the Pupil

Point of regard techniques estimate the centre of the pupil as part of the process of assessing fixation position. An inherent problem with this is that with eye rotation away from the recording axis the pupil appears to become more elliptical in shape. Viewed 'head-on' from the same axis it appears circular. These techniques have to estimate the pupil centre by some 'goodness of fit' computational procedure. The pupil or limbus can by itself give a measure of eye rotation by simply using the measure of the degree of apparent ellipticity (Young and Sheena, 1975b). Bechnai and Hallett (1977) have recently provided an algorithm to accomplish this.

5.4.9. Double Purkinje Image

A light source gives rise to other reflections besides the corneal reflection which is the first Purkinje image. Three other reflections occur at the various interfaces within the eye. The rear surface of the cornea gives rise to a second dim image, with the third and fourth Purkinje images being given by the front and rear surfaces of the lens respectively. The fourth real image is formed in the same plane as the first image. The third image is virtual and is both more diffuse and formed in a different plane to the others. The separation between the first and fourth Purkinje images alters for an eye rotation but not for a translation of the eye and measurement of this separation has formed the basis of an eye measurement technique (Cornsweet and Crane, 1967; Cornsweet and Crane, 1973).

An infra-red light source is used to create the two Purkinje images in the plane of the pupil of the eye. Suitable collection optics record these two images and effectively separates them so that each image is centred on a separate four-quadrant photocell. As the eye rotates the outputs from these photocells are used to control both a movable mirror (which keeps the first Purkinje image centred on one photocell) and to position the other photocell so that the fourth Purkinje image is centred on it. Eye translation causes an appropriate movement of the mirror whereas eye rotation results in a movement of the latter photocell. The output of this photocell is essentially used to give the eye position information.

The system is remote from the S and has an accuracy of about 1' over a range of 10-20^{o} diameter, this being effectively limited by the diameter of the pupil.

5.4.10. Ultrasound

Piezo-electric ultrasound transducers mounted in goggles have recently been employed (Haines, 1977) for measuring eye movements. Due to the fact that eye rotation does not occur around a fixed point a change of the sound reflective contour of the eye takes place with rotation which can be detected by using ultrasound. This can be accomplished even through the eyelids when the eyes are closed. Unfortunately, the transducers effectively occlude nearly all vision, but are useful for recording eye tremor with eyes closed. No accuracy figures are given for this technique although linearity and signal to noise ratio of the response signal is good.

5.5. EVALUATION AND TECHNIQUE SELECTION

The major requirement for a technique for the present purposes was that it would permit recording of eye movements whilst the S was viewing a stimulus that subtended some 20 - 25^{o} visual angle. This had to be achieved so that the S was unaware of the fact that his eye movements were being recorded (c.f. Chapter

2). The required accuracy of the device was approximately 1^{o} visual angle as the interest was in saccadic eye movements.

The contact lens technique is the most accurate, but is of limited range and more appropriate for the study of miniature eye movements. Contact lenses are also expensive, uncomfortable and potentially hazardous to the S. The double Purkinje image approach is almost as accurate but requires a high level of incident light to elicit a recordable fourth Purkinje image. It is also limited in its field of view, Young and Sheena (1975b) reporting $\mp 15^{o}$, although it has the advantage of being somewhat remote from the S. Limbus techniques are the next most accurate but require some form of spectacles mounting and fairly obvious setting up for each S. Corneal reflex methods and EOG recording were rejected for similar reasons of awareness to the S, EOG also not meeting the required accuracy of measurement. Some form of point of regard system thus seemed to offer the best advantages. The oculometer approach was very attractive in that it is completely remote from the S but at the time both the software developments and apparatus requirements were considered to be too complex for the experimental task envisaged.

The system selected was a point of regard technique using multiple light sources. This would permit recording of eye movements over the required range with an accuracy of about 1^{o}. Mackworth's wide angle camera (1968) method was interesting in that the S essentially sat at a box viewing the stimulus with the camera recording the corneal reflection of the stimulus from the S's eye, via a half silvered mirror. Thus the S could be unaware of the recording camera. However, the accuracy of this method is low, Mackworth reporting 1.9^{o}. A commercial instrument based on this technique (Polymetric Company) has a lower accuracy figure of $\mp 2.5^{o}$ (Young and Sheena, 1975b). The multiple infra-red light source technique (Cowey, 1963) was preferable to the use of bright illuminated scales, as in Mackworth's approach, as the former reduces the S's awareness of any recording.

Accuracy figures for the multiple light source approach are not usually given as the technique is typically used with newborn infants. Where such data is reported the figures given are quite gross. Cowey (1963) employed adult Ss fixating points separated by some 5^{o}. Salapatek, Haith, Maurer and Kessen (1972) report an average error of ∓ 4-5^{o} again with adult Ss. The measurement errors of the technique have been well detailed (Slater and Findlay, 1972a, 1975b ; Bullinger, 1974) and so it was decided to adopt this proposed hybrid method and then apply suitable corrections to the data to improve accuracy.

5.6. THE EYE MOVEMENT RECORDING METHOD

5.6.1. Introduction

Some preliminary trials were conducted with the apparatus developed for infants by Slater (1974). These trials demonstrated that, in principle, the multiple light source technique could be modified as suggested in the previous section. As a result the following apparatus was designed and constructed.

The apparatus is schematically shown in Figure 5.1 and consisted of a large 'box' with a movable rear projection screen at one end and a face mask at the other. A system of three projectors presented either stimulus slides or an intervening blank visual field with or without a fixation cross upon the screen. Ss sat with their heads resting against the mask and viewed the screen through a large half-silvered mirror by means of which a video record of their eye movements could be obtained using the camera in the adjoining light-proof box. All internal and external surfaces of the two boxes were painted matt black.

The camera not only recorded both the corneal reflections of four infra-red light emitting diodes placed around the stimulus as well as sufficient eye

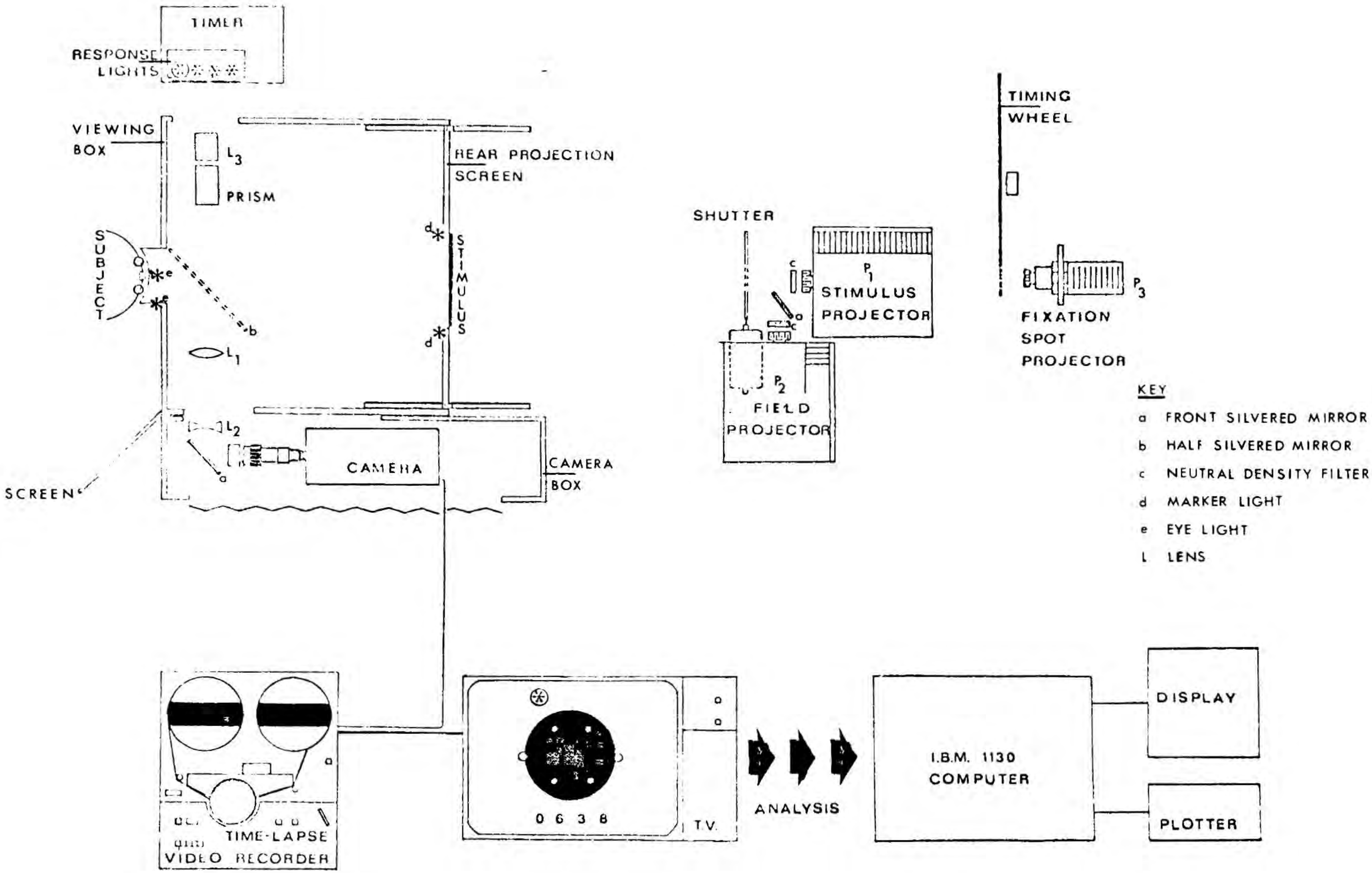


Figure 5.1 Diagram of the stimulus presentation and eye movement recording equipment.

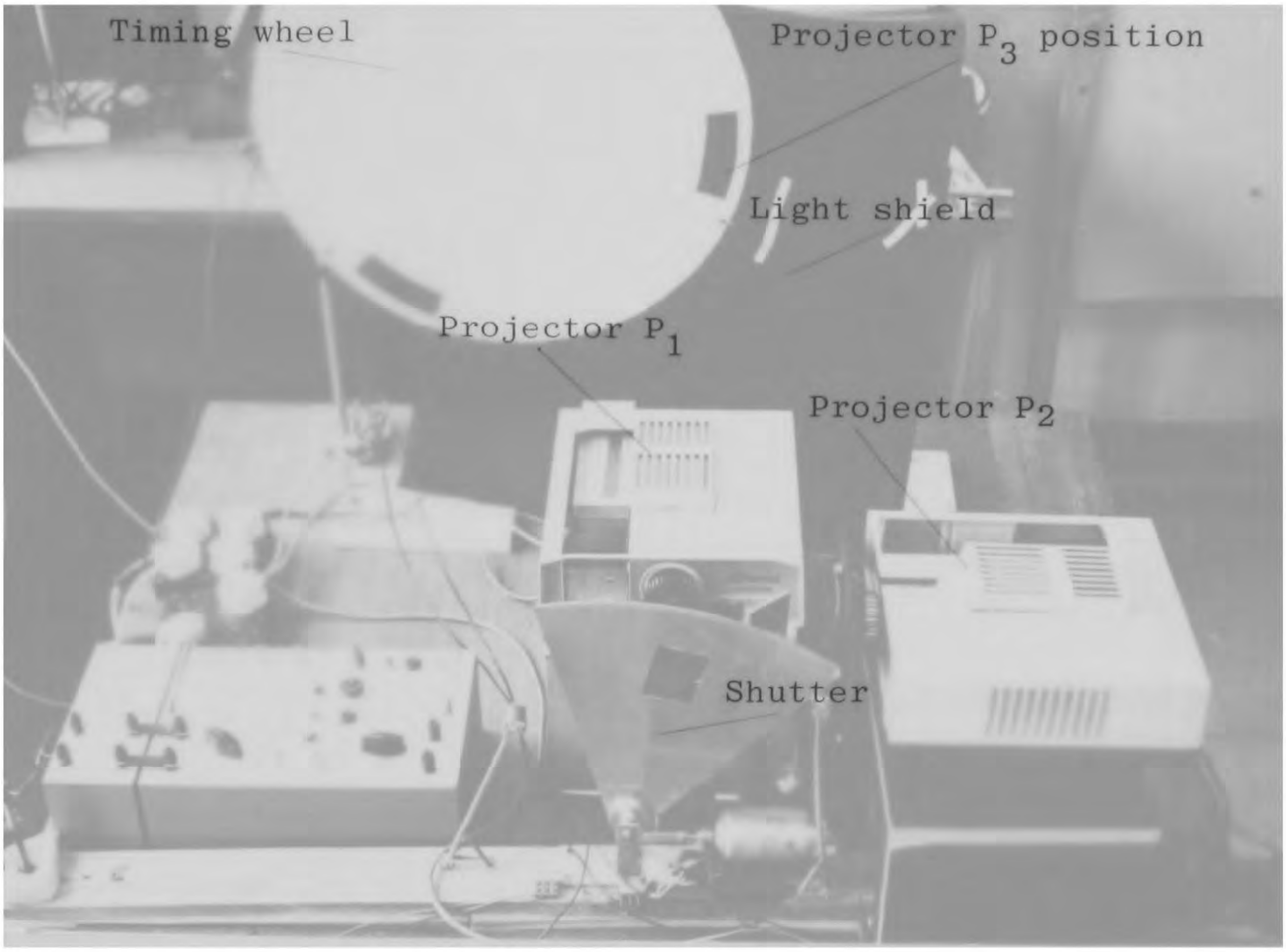
detail to enable the pupil boundary to be determined, but also the S's responses and the length of time the stimulus was viewed.

For the purpose of exposition the apparatus is considered as four inter-related systems: projection, viewing, recording and response systems.

5.6.2. The Projection System

A system of projectors was devised so as to essentially produce a projection tachistoscope with the stimuli being shown on a rear projection screen. Three projectors were used to achieve this. One served to present the stimuli, the second producing an inter-stimulus field of matching luminance to the stimuli. The remaining projector provided for the addition of a fixation cross to the inter-stimulus field. The projectors were set up so as to be able to provide an automatic 5s inter-stimulus interval with the fixation cross only being presented during the final second. Stimuli could be shown for any length of time. The apparatus is described and then its operation detailed. It is shown in Figure 5.2.

Two matching automatic projectors (Gnome Rotauto) were mounted at 90^{o} to one another with one of them directly facing the rear projection screen. This latter projector (P_1) was used to present 35mm stimulus slides. The other



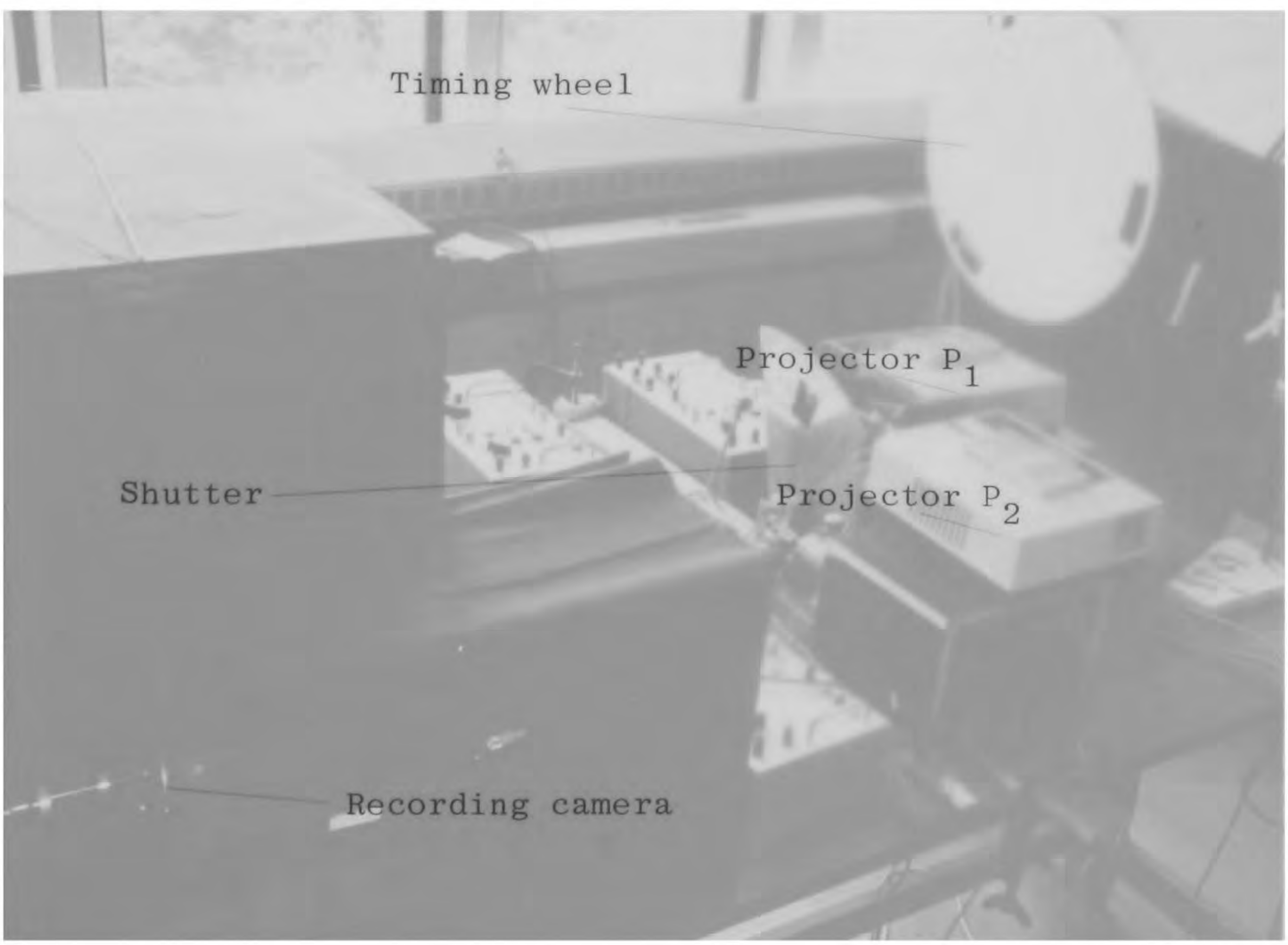
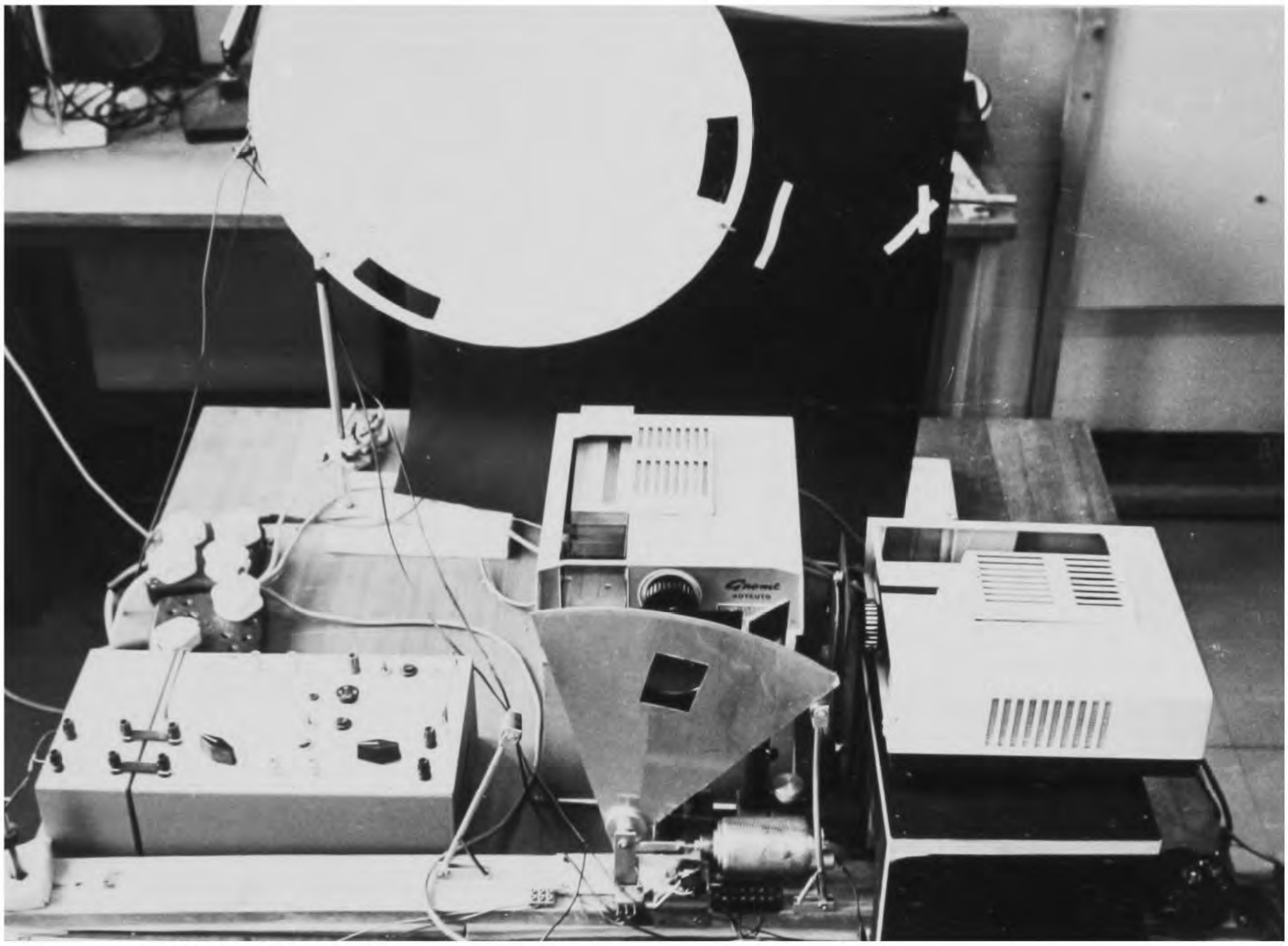


Figure 5.2 Two photographs showing the arrangement of the projection system.



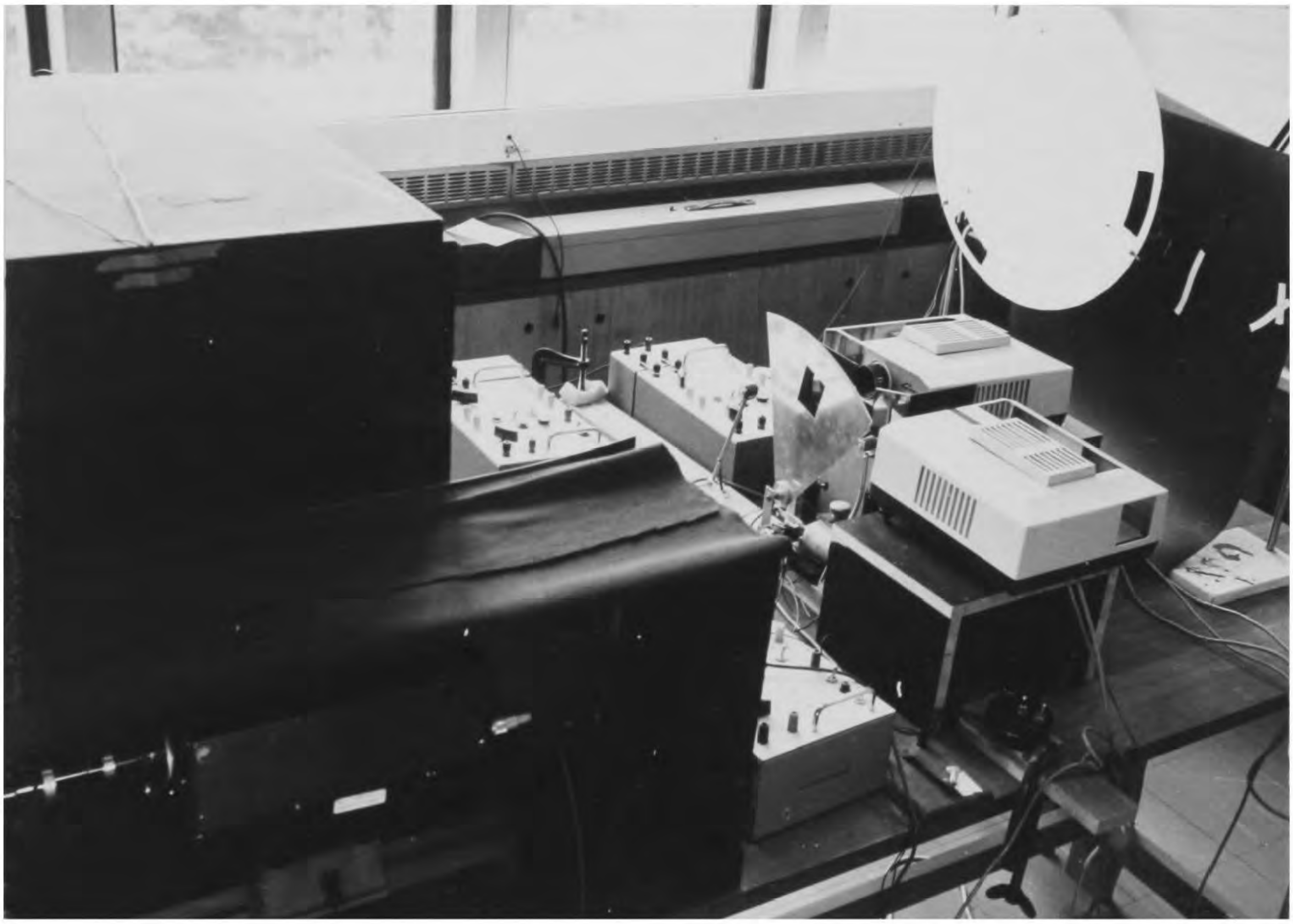


Figure 5.2 Two photographs showing the arrangement of the projection system.

(P_2) projected a blank visual field of similar brightness during stimulus changes. Both projectors were fitted with matching 0.1 neutral density filters to reduce lens flare upon the rear projection screen.

Projector selection was achieved by means of an electro-mechanical shutter in front of P_1 and the reflected beam of P_2 from a flat front surfaced mirror. The projectors were so arranged that the optical distance of both to the shutter was the same. The shutter consisted of a solenoid operating a hinged aluminium quadrant. Operation of the solenoid caused the quadrant to move laterally hence permitting one or other projector beams to pass through an approximately rectangular hole near its outer edge. This movement also operated three microswitches (MS1, MS2, MS3), at the quadrant base. The speed of crossover of this hole between the light paths of the two projectors was such that the change from P_1 to P_2 appeared virtually instantaneous when viewed from the S's position. Sprung rubber stops at each end of the quadrants travel completely damped any resulting oscillation of the rectangular hole across the light beams when the solenoid was operated. The whole shutter assembly was mounted on a piece of wood which was then attached to the bench using foam rubber and G-clamps. This prevented any vibration from the solenoid being passed on to the half silvered mirror.

A third projector (P_3, Leitz- Pradix) was mounted above and slightly behind P_1. This was used to present a small fixation cross superimposed upon the blank visual field of P_2 such that the cross was of higher light intensity. This was provided by a slide containing this cross with the rest of the surrounding field blacked out. The fixation cross, as projected, subtended approximately 1^o visual angle overall to the S.

This projector, P_3, was housed behind a shield to eliminate stray light and was directed at the rear projection screen through a rotating timing wheel which permitted the projection of the fixation cross for a known length of time. By having the timing wheel directly in front of the lens of P_3 and by utilising only a small central portion of the projector beam, fast rise and fall times of the projected cross was ensured. The timing wheel consisted of a large disc of thick card, revolving once every 15s and driven by a Crouzet motor. The card had three equally spaced sections near its perimeter removed. These sections rotated immediately in front of P_3 taking 1s each to traverse the projector beam. Beside each section was a small projecting solder tag used to momentarily trip a microswitch (MS4) mounted on the wheel support stand.

A sheet of frosted acrylic (ICI - Frost 900) was used as the rear projection screen with a suitable area marked off by masking tape as the stimulus presentation area (Figure 5.3). All stimulus slides were aligned to the inside top and sides of this masked area prior to an experimental run.

<u>Projection system operation.</u> Figure 5.4 represents a schematic diagram of the wiring of the projection system. It shows the solenoid-operated shutter in the 'off' position so that the stimulus was seen by the S. Operation of push button S_1 temporarily switched the solenoid on causing the shutter to change over from the stimulus projector, P_1, to projector P_2. Shutter movement closed all three microswitches: MS1, MS2, and MS3. MS4 would already be on (being set to only momentarily trip off) thus the solenoid would be held in the on position even when S_1 was released. If the timing wheel had been switched on (S_3) then through MS2 closure this would begin to revolve. After 5s then MS4 would be momentarily tripped off by one of the tags on the wheel thus switching off the solenoid and also through MS2, the timing wheel. The subject once again would be presented with P_1. This arrangement enabled a 5s inter-stimulus interval to be presented.

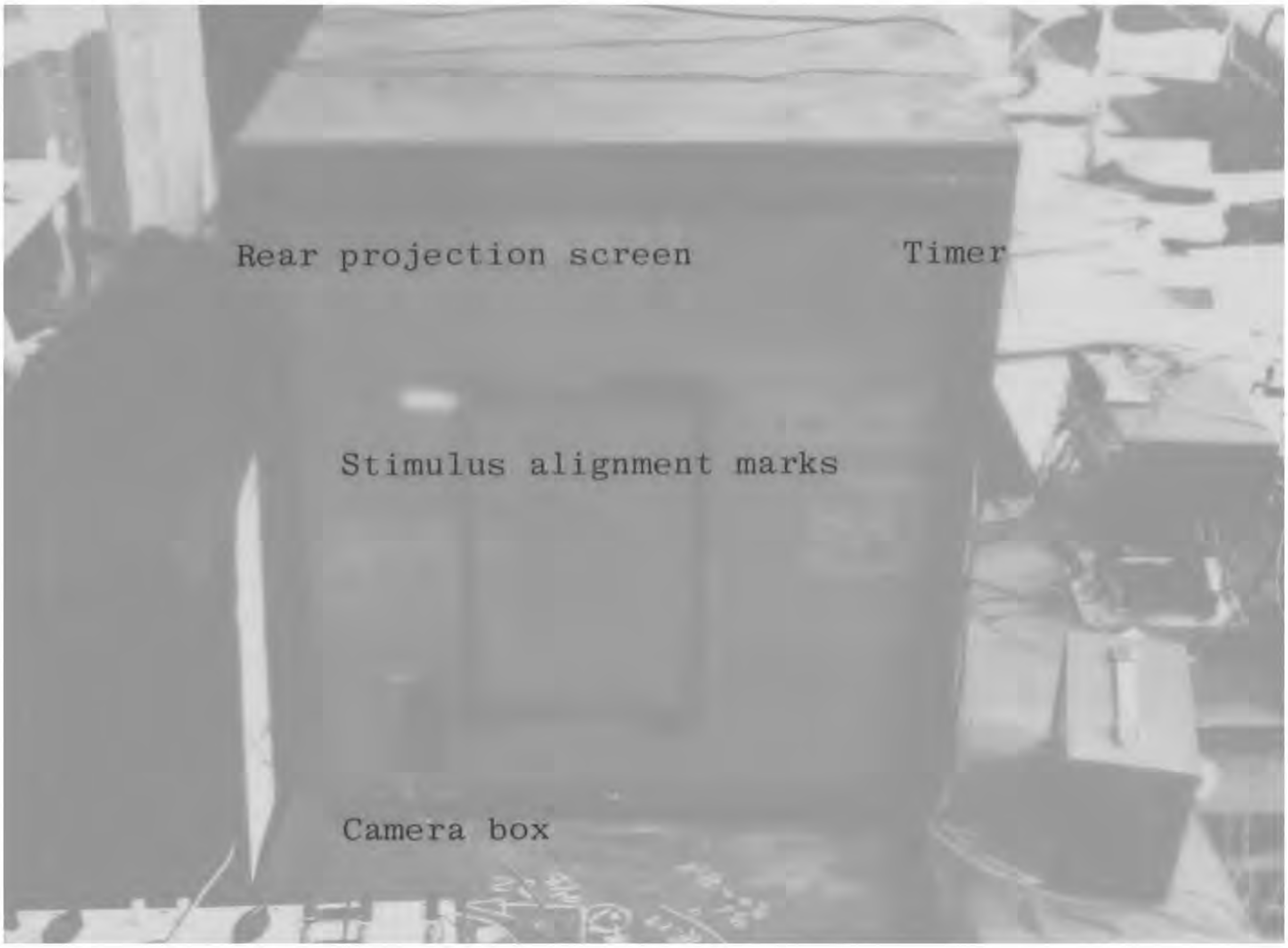


Figure 5.3 The rear projection screen as seen from the projectors.

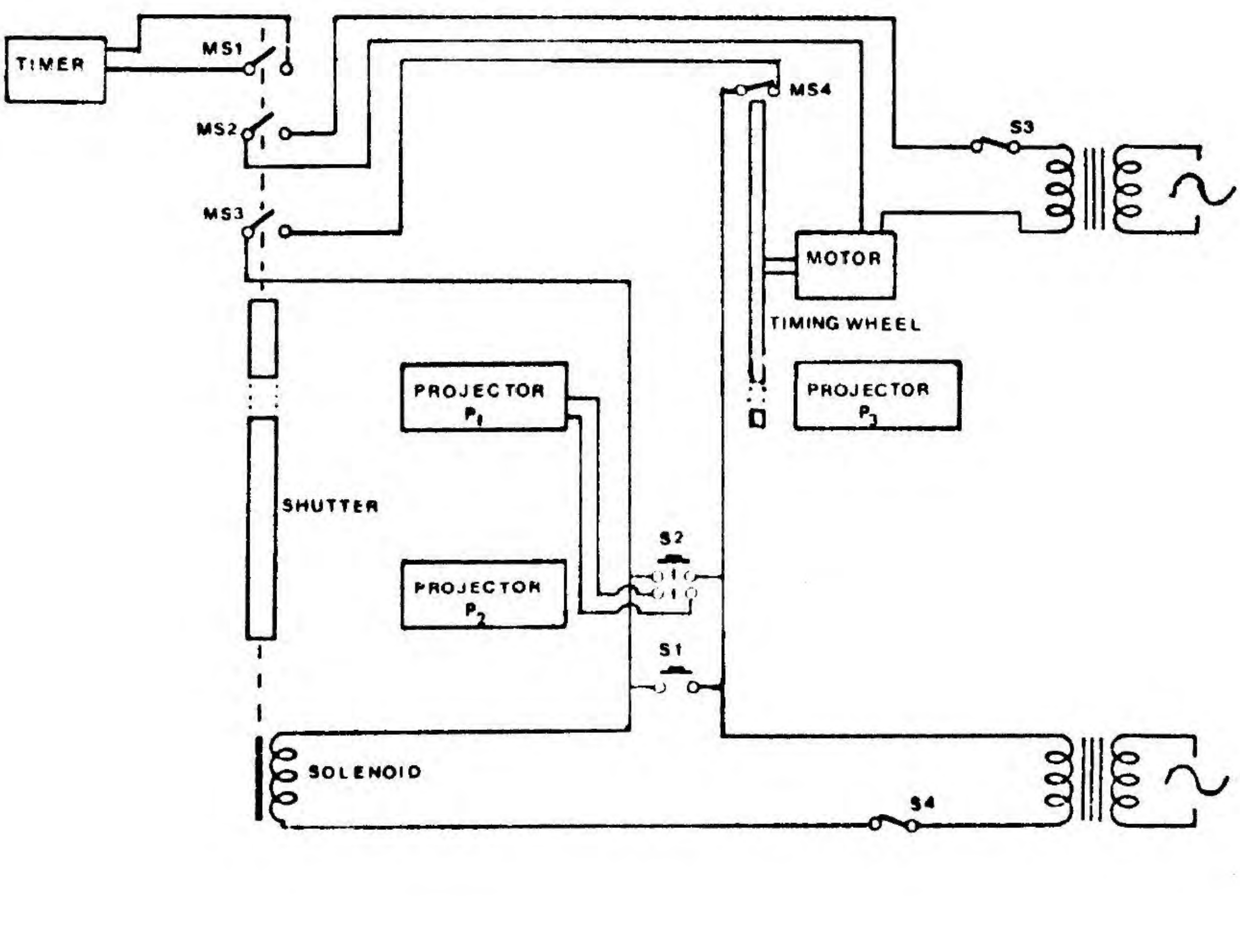


Figure 5.4 Layout of the various components of the projection system.

Figure 5.3 The rear projection screen as seen from the projectors.

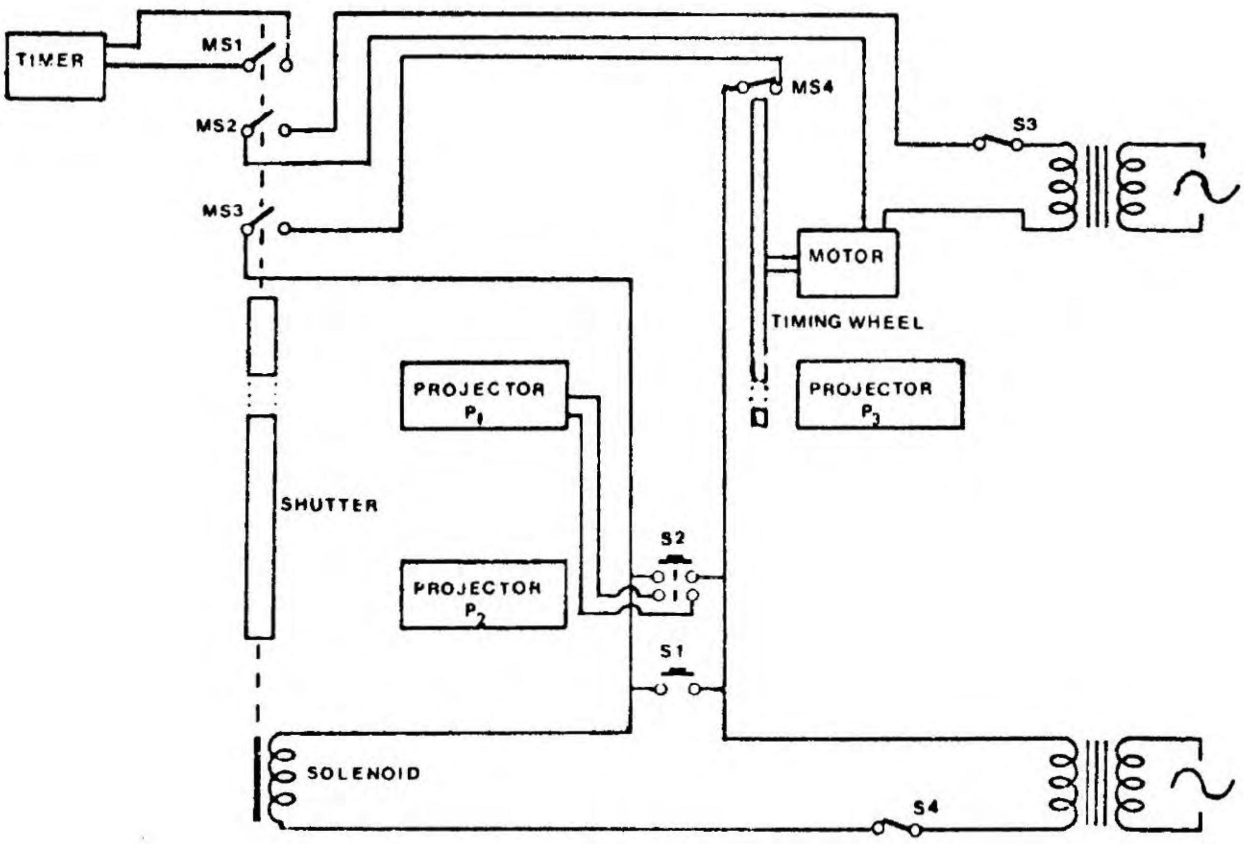


Figure 5.4 Layout of the various components of the projection system.

Each of the three 5 second segments of the timing wheel consisted of 2 sections: a solid segment representing 4 seconds rotation followed by a cut-out sector taking one second to traverse the beam of projector P_3. When MS4 was tripped off, the rotating wheel effectively cut off P_3 also. This permitted the fixation cross to be presented by P_3 for the last second of the inter-stimulus interval.

Changeover from P_1 to P_2 caused the timer (Advance Timer), through MS1 operation, to reset to zero. Reverting to P_1 initiated the timing again. Great care was taken in the siting of MS1 so that the counter started at the instant the projected stimulus struck the rear projection screen. The timer was picked up by the television camera and provided a record of the stimulus presentation time.

Longer inter-stimulus intervals could be obtained by having the timing wheel switched off - in this case P_2 was viewed until the solenoid power supply was turned off via S_4. The stimulus projector could be on for any length of time until push buttons S_1 or S_2 were operated. Push button S_2 operated the system in a similar fashion to S_1 except that it also produced a change of stimulus slide during the blank field presentation.

5.6.3. The Viewing System

A rubber mask fixed to the front of the box together with an adjustable chin rest mounted beneath it on a small optical bench served as a head restraint for the subject. This is shown in Figure 5.7 . The rear projection screen and its associated marker lights panel were attached to a movable metal frame and positioned at the rear of the box. A vertical rectangle 30.5 cms x 20.3 cms was cut out of the aluminium sheet marker panel. The centre of this rectangle was aligned to the centre of the face mask. The marker panel was mounted 3 cms in front of the projection screen. The marker panel and screen being positioned so that this rectangle subtended 24^{o} vertically x 16^{o} horizontally to the position of the S's right eye. The S being some 72 cms from the panel. Figure 5.5 shows this arrangement. The area of the rear projection screen visible at the viewing distance was 31.8 cms x 21 cms. This area was outlined by masking tape on its rear surface for ease of projector alignment.

5.6.4. The Recording System

The recording system encompassed the marker lights, the eye lights and the video equipment.

The marker lights were four light sources positioned around the stimulus and which provided the corneal reflections from which the measurement

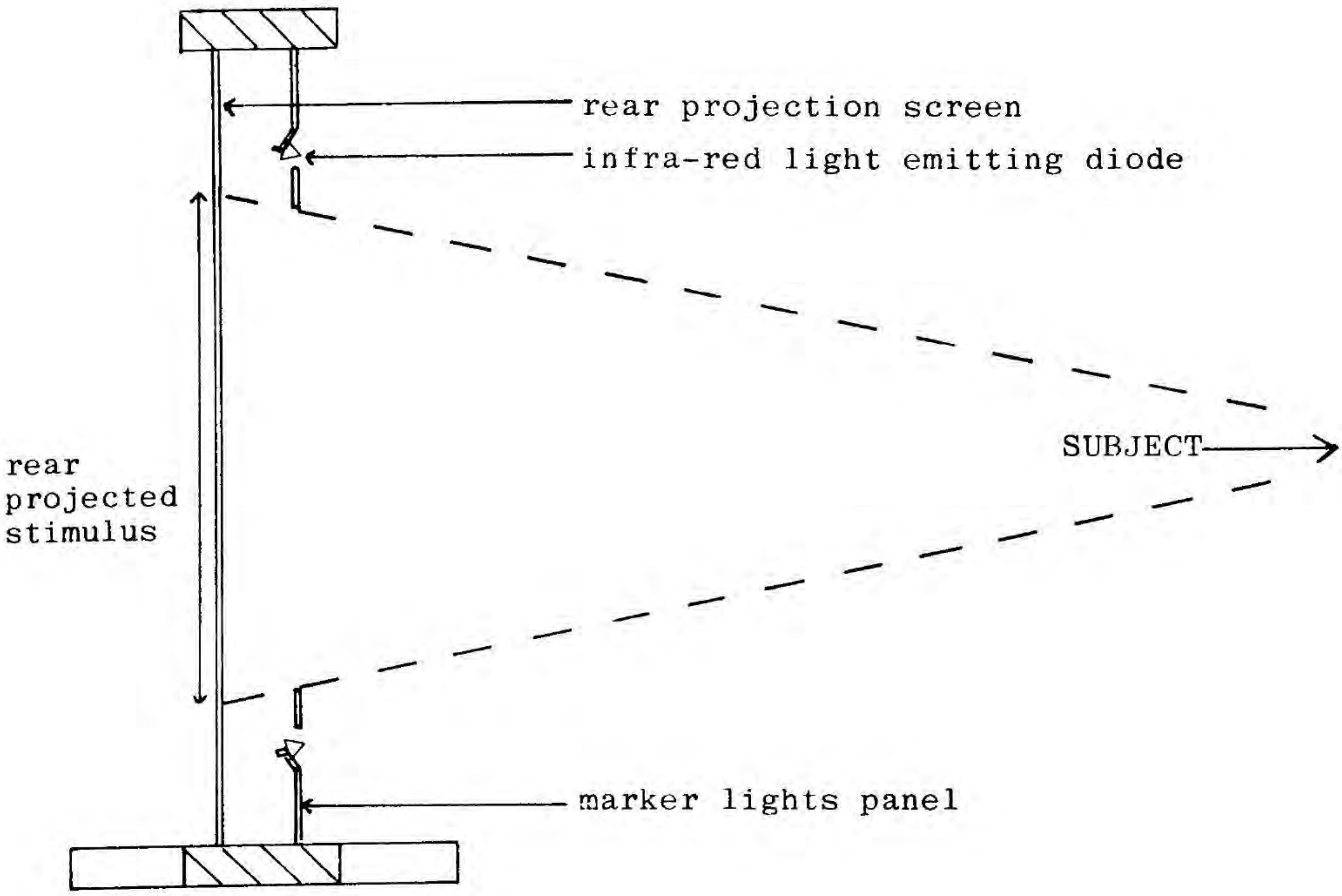


Figure 5.5 Side view of the rear projection screen.

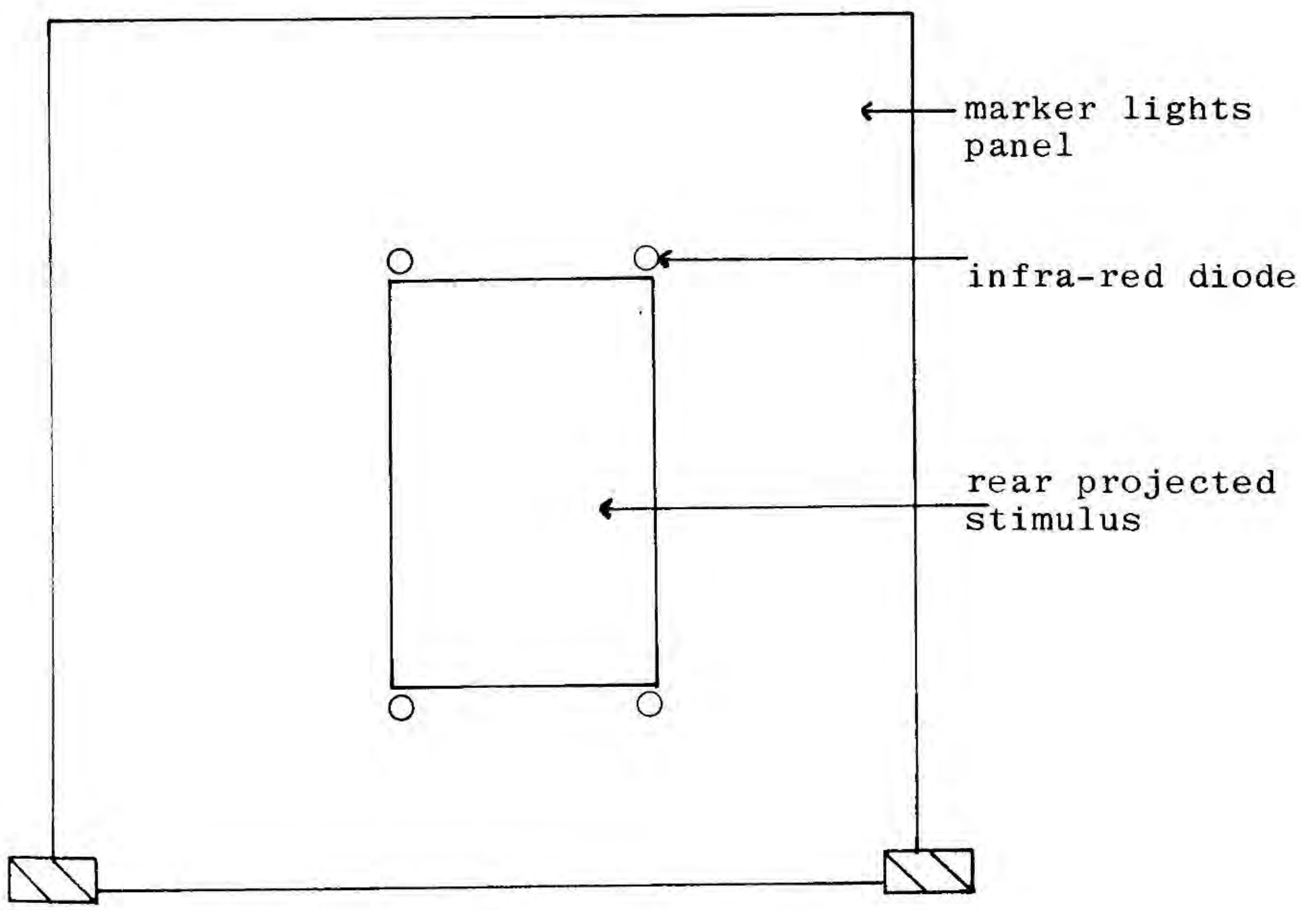


Figure 5.6 Front view of the rear projection screen.

of fixation position was eventually derived. In contrast to other systems (e.g. Slater and Findlay,1975a; Salapatek and Kessen,1966; Haith,1969) which use illuminators fitted with suitable filters to limit the incident light on the eye to a band of infra-red energy, the present system used small infra-red light emitting diodes which have a very narrow spectral bandwidth and so require no further filtering. This, together with their low power output make these ideal sources from an eye safety point of view (see later section). It had been hoped that the illumination from the marker diodes would have been sufficient to not only provide bright corneal reflections but also to provide adequate contrast at the eye to enable registration of the pupil boundary. This proved not to be the case. The marker lights did provide sharp corneal reflections, but the eye was only dimly illuminated. Two of the same diodes were thus mounted in the right eye piece of the face mask to illuminate the pupil, these lights being called here the eye lights.

The marker lights. Four Monsanto ME5A infra-red light emitting diodes (LEDs) served as the marker lights to provide the corneal reflections from which the eye position could be calculated. These were centrally mounted in four 1.25 cms diameter holes cut in the marker panel at 18.75 cms radius from the centre of the cut out rectangle.

These holes were positioned 60^{o} vertically either side of the horizontal through the centre of the rectangle (see Figure 5.6). The front of the LEDs were in line with the front surface of the marker panel. The four LEDs subtended a rectangle 26^{o} x 15^{o} horizontally to the S's position. Copper strips attached the diodes to the rear of this panel at a point further out along the radii such that the diodes could be angled in towards the centre of the viewing mask. Both these copper strips and the aluminium sheet of the marker lights panel acted as heat sinks. All four diodes were run at 15V from a power supply (Radford LAB59R labpack)through four wire-wound resistors (100Ω). The resistors were attached in parallel to a bus bar and mounted horizontally to permit maximum heat dissipation.

The eye lights. In order to enhance the contrast between the pupil and iris boundary two ME5A LEDs were mounted in the right eye piece of the rubber mask. Both LEDs were mounted on copper strips attached to bronze positioning bars which also acted as heat sinks. One of the diodes was suspended from the top centre of the mask and the other was mounted on the optical bench (see Figure 5.7). All metal parts within the mask were painted matt black. These eye lights were run at 6V through series wire-wound resistors (10Ω).

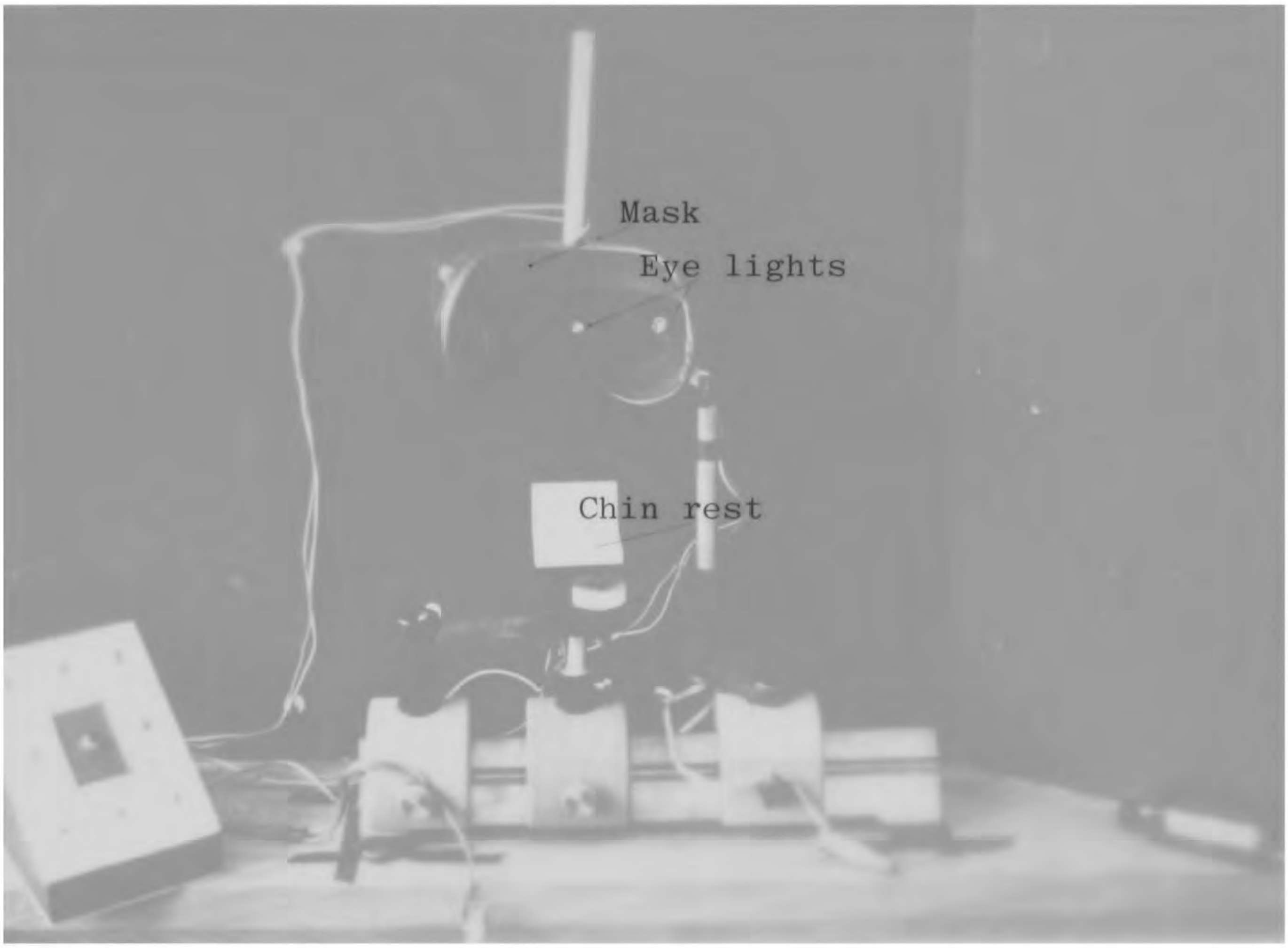


Figure 5.7 The mask and chin rest
various response buttons

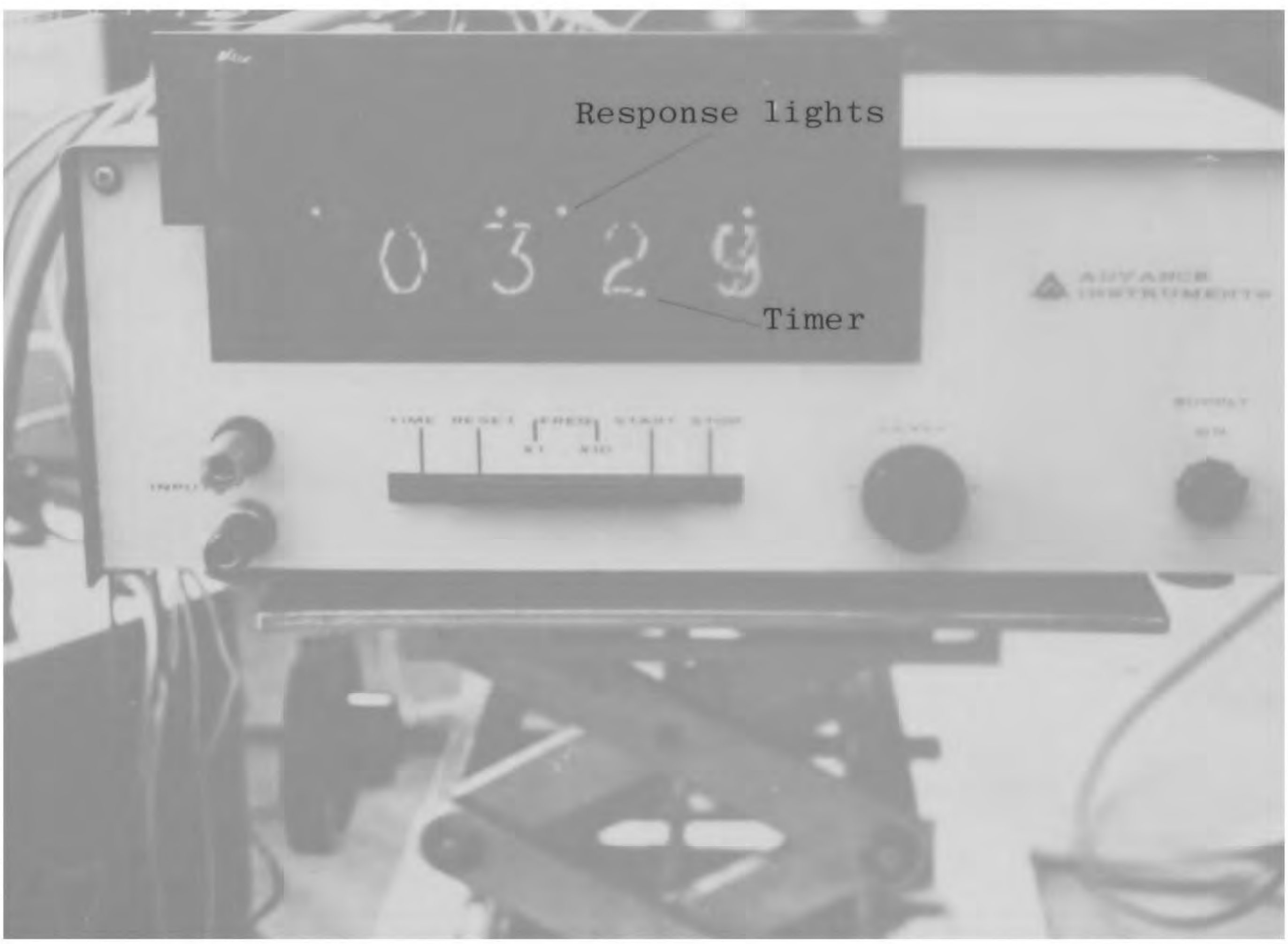


Figure 5.8 The response lights and timer.

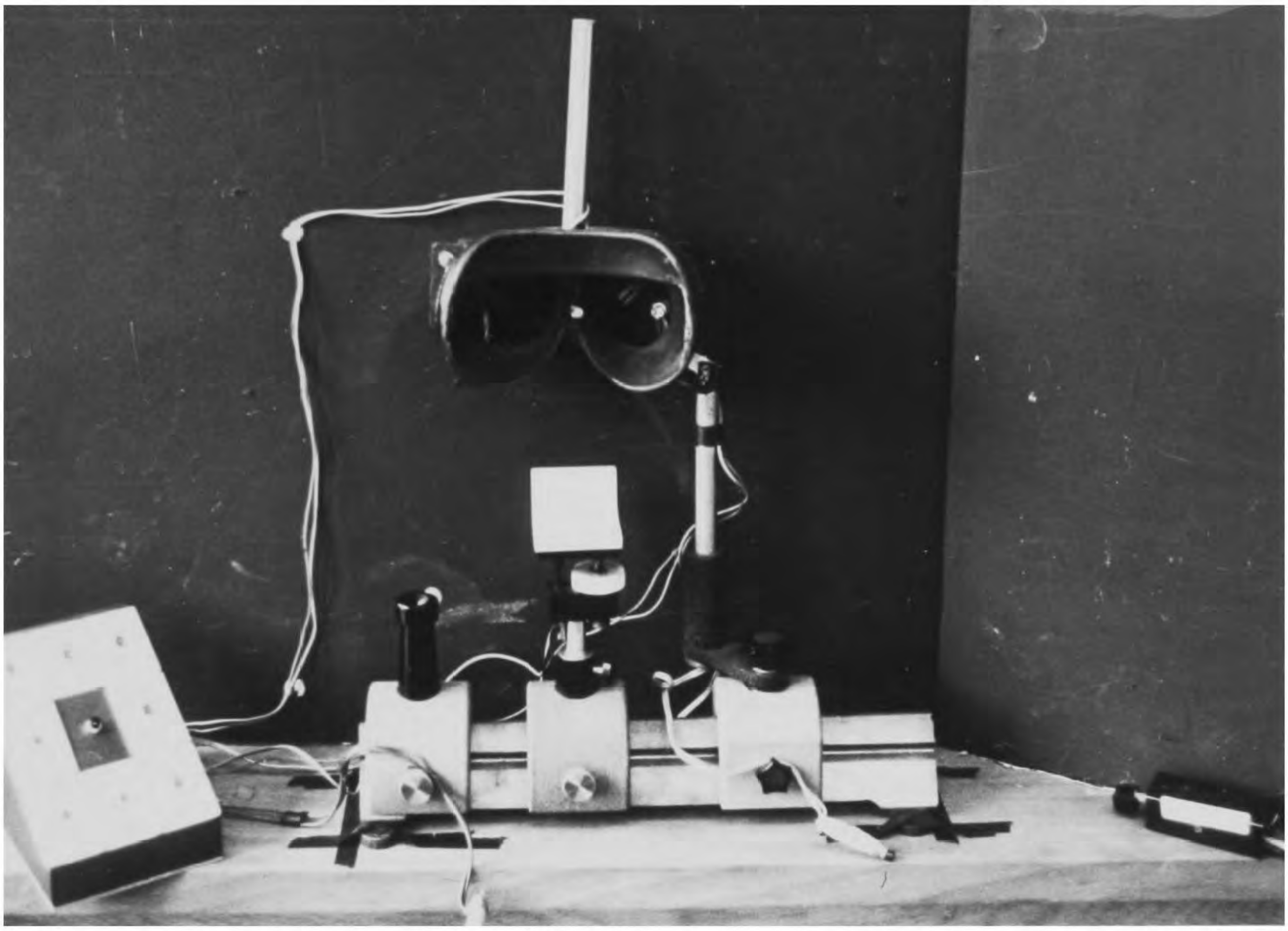


Figure 5.7 The mask and chin rest. The 2 eye lights and various response buttons are also shown.

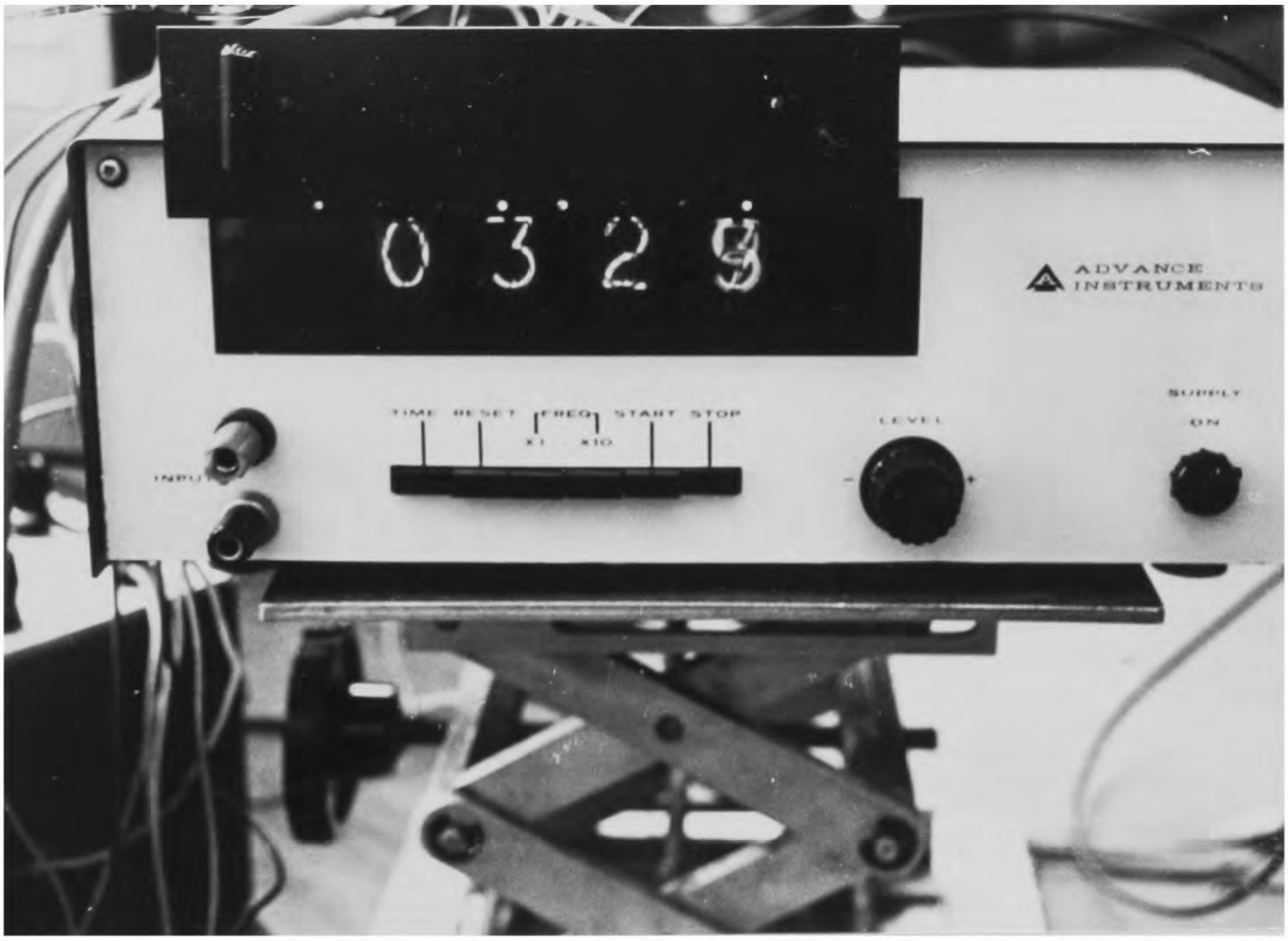


Figure 5.8 The response lights and timer.

Using an experienced subject the LEDs were vertically aligned with the centre of the pupil of the right eye as the S was fixating a centrally presented fixation cross. The LEDs were then angled in towards the eye so that good contrast between the pupil and iris was obtained on the television monitor.

Infra-red radiation hazard. The use of infra-red light poses a possible eye radiation hazard which must be considered in constructing any eye movement monitoring device which utilises it. Designers of oculometers are particularly aware of this although it is a factor which is often not considered in other systems. Craske and Smith (1975) give a rare mention of this hazard for their limbus technique.

The possible infra-red hazards are: the production of cataracts, lesions, flash burns of the cornea and lenticular changes. Incident energy on the eye is increasingly absorbed by the ocular media as the wavelength of that energy increases in the near infra-red range of 780-1400 nm. Between 1400-1900 nm the incident energy is mainly absorbed by the cornea and aqueous, beyond 1900 nm the cornea is the sole absorber. Damage to the eye is caused by the absorption of this energy which can also be conveyed to other eye tissues, as well as the absorbent ones, and causes temperature increases in these tissues. Protection against possible damaging high energy doses is commonly provided by the blink reflex (Sliney and Freasier, 1973).

The infra-red corneal dose rate due to daylight is approximately $10^{-3}W.cm^{-2}$, thus a safe chronic ocular exposure value of $10^{-2}W.cm^{-2}$ for near infra-red has been advised with a long term chronic value of 10 $mW.\ cm^{-2}$ and short (several minutes) exposure of $100mW.cm^{-2}$ (Sliney and Freasier, 1973). On the assumption of 40% transmission of incident energy by the pre-retinal ocular media, Clark (1967, 1968) has arrived at a figure of $125mW.cm^{-2}$ for the intensity at the retina likely to cause permanent impairment of retinal function in long doses.

The infra-red LEDs used had a peak emission wavelength of 900 nm and a spectral line half-width of 40nm. The ocular irradiance was measured with a United Detector Technology 40x Opto-meter fitted with a radiometric filter which gives a linear response from 450nm to 950nm. The values obtained for each marker light at the S's viewing distance with the interposed half silvered mirror was $5uW.cm^{-2}$. Similarly the value for each eyelight was 118 $uW.cm^{-2}$. A total corneal irradiance figure of some 256 $uW.cm^{-2}$ was, therefore, used and this is some 2.6% of the safe ocular chronic value given by Sliney and Freasier and was thus judged unlikely to cause any harmful effects.

The criterion adopted in setting up the supply voltages for the LED's was that of obtaining a useable television picture with minimal ocular irradiation.

The video recording system. The television camera (Link 106) was fitted with a 2.5 cms silicon diode tube (R.C.A. 4532/AMR) which had a high sensitivity in the near infra-red region.

An enlarged image of the eye was attained by using a Dallmeyer telephoto lens (150mm, F3.5) fitted to the camera with three extension rings. A combination of bi-convex (L_1) and bi-concave (L_2) lenses effectively produced a telescope in front of the camera assembly. A large half-silvered mirror (20.0 x 14.5 cms), completely covering the S's binocular view of the stimulus, permitted a direct camera view of the S's right eye without disturbing his view of the rear projection screen and without the S's awareness of the camera. A front silvered mirror directly in front of the camera permitted it to be mounted in a small light proof box adjacent to the main one (as shown in Figure 5.1). By altering the position of lens L_1 and refocusing using L_2 a different sized image of the right eye could be obtained whilst at the same time providing a shallow depth of field. This arrangement had two advantages. First a suitable monitor image size of the eye could be selected for analysis purposes and secondly the shallow depth of field, together with the goggles and chin rest combination, restricted head movements to about 1.3 cc. Lateral head movements greater than this being physically prevented whilst a large fore-aft movement rendered the monitor image of the eye unfocussed and consequently unscorable. Cowey (1963) has demonstrated that lateral movements of this order do not affect the accuracy of the multiple light source techniques.

A combination of lenses L_3 and a reversing prism brought a reduced upright image of the timer and response lights to the same focus as the S's eye. Sharp focussing of the eye and timer-response lights combination was achieved by means both of the focussing ring on the camera and also by slightly altering the position of lens L_2. Slight adjustments to the final focus of the timer and response lights could be made by adjusting the position of lens L_3 and associated prism.

Lateral location of the television image of the eye in the centre of the monitor was accomplished by slight alteration to the lateral position of the half silvered mirror. Vertical location of the eye was achieved by adjusting the height of the chin rest. Both of these operations were carried out whilst an experienced S fixated a centrally presented fixation spot.

The camera was connected to a video recorder (Shibaden SV612E(K) time lapse recorder) and a television monitor. The video recorder enabled the replaying of the recorded eye movements at various different speeds together with the facility to stop the picture to examine any particular part of the data.

5.6.5. The Response System

In order to provide an indication on the video record of a response made by the subject some small red LEDs were mounted above the timer as shown in Figure 5.8 . By noting the position of the response light with respect to the timer numerals the appropriate response could be recorded.

Three types of response buttons were available to the subject:

1) Two hand-held push buttons. These were connected to two of the response lights.
2) An array of push buttons with each button connected to a different response light.
3) Switch S_2 could be used by the subject as well as by the experimenter to control stimulus slide termination and advance to the next slide.

The timer was initiated by presentation of a stimulus and automatically reset to zero at the end of such presentation. Stimulus presentation time was recorded in units of .01s. Due to the Nixie lights used in the timer and the response red LEDs the resultant television picture of the S's right eye also displayed the superimposed timer numerals and the small white 'spots' caused by the response lights. Both timer and response lights were mounted on a table of adjustable height so that their image could be positioned anywhere on the monitor so as not to obstruct the picture of the eye (Figure 5.9).

5.7. OVERVIEW OF THE EYE MOVEMENT RECORDING METHOD

The purpose of the apparatus described in the previous section was to produce an enlarged image of the S's right eye on the television monitor as shown in Figure 5.9 . The corneal reflections of the marker lights are shown here as are the 2 eyelights which enhance the contrast between the pupil and the iris. Sometimes an eyelash obliterated the image of one of these marker lights. Also shown on the monitor is one of the response lights and the timer numerals indicating the S's response and the stimulus presentation time respectively.

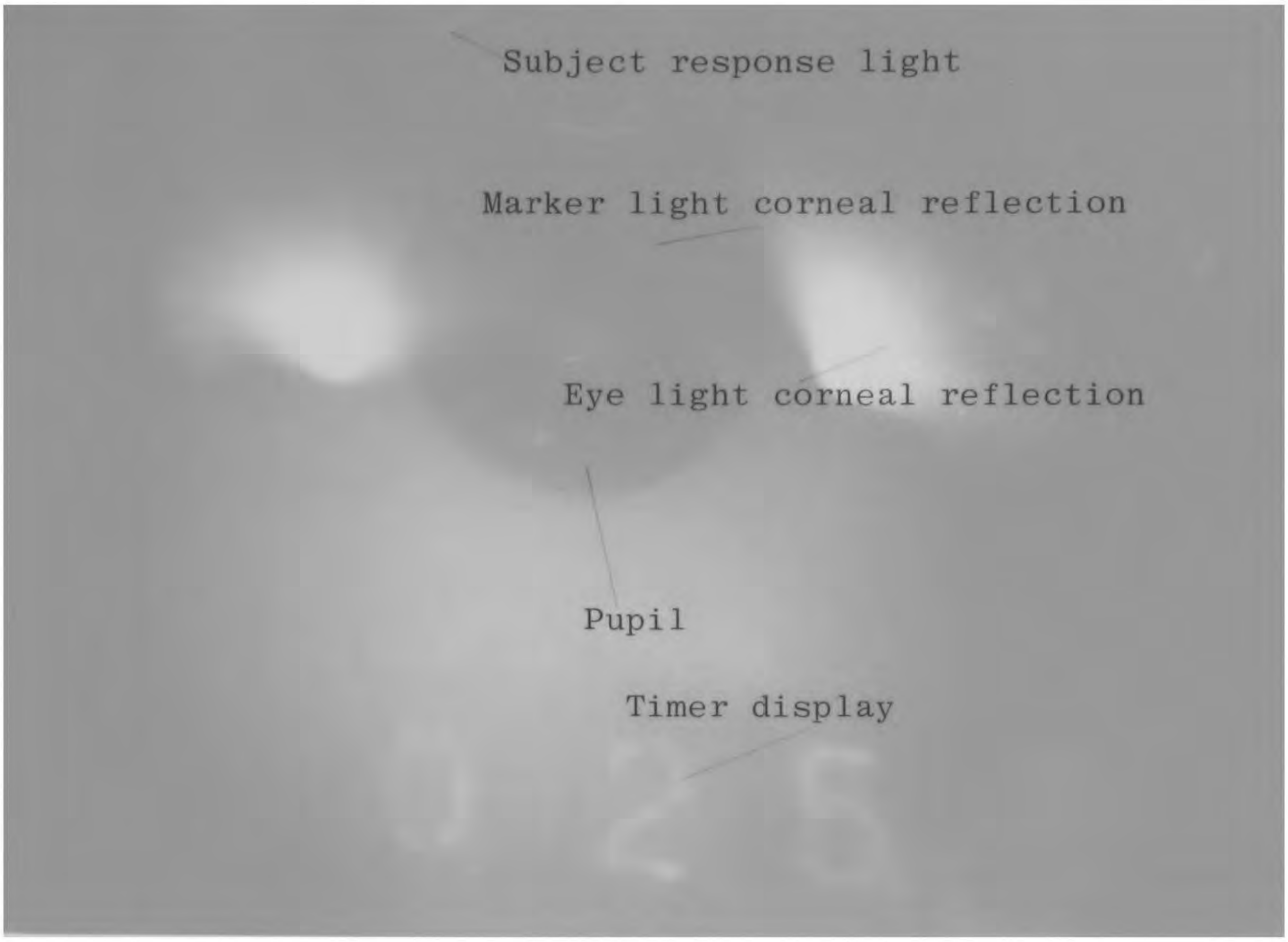


Figure 5.9 The resultant picture of the subject's right eye on the television monitor.

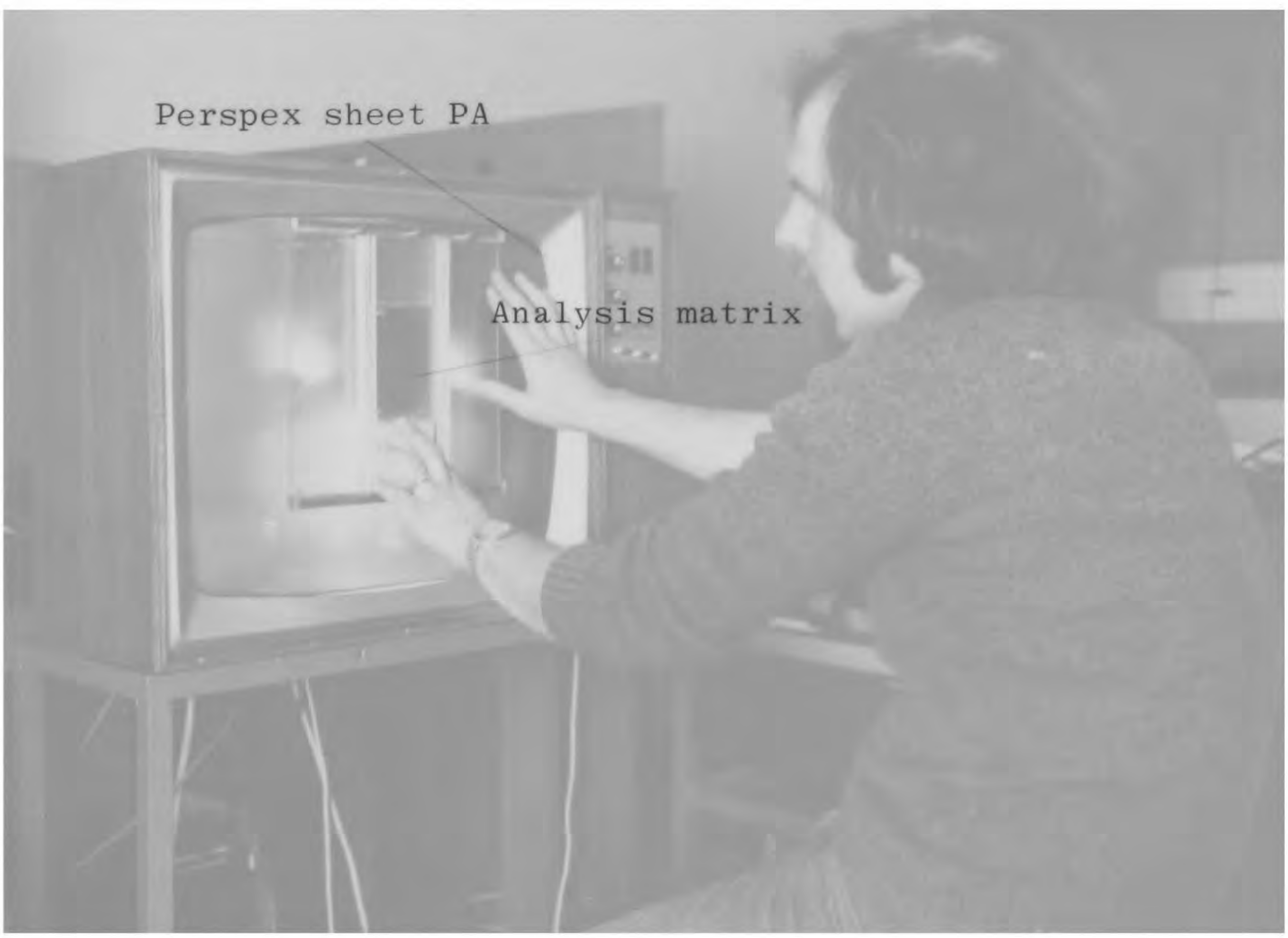


Figure 5.10 Measuring the subject's fixation position.

Figure 5.9 The resultant picture of the subject's right eye on the television monitor.

Figure 5.10 Measuring the subject's fixation position.

The equipment permitted sharp focussing of the corneal reflections together with the ability to alter the size of the eye image on the monitor. The response lights and timer could be positioned anywhere on the monitor picture. All this could be achieved without the S's knowledge that his eye movements were being recorded.

Great care was taken in setting up the camera and monitor to obtain this picture. First a test card was recorded on video tape and replayed through the monitor to check its linearity. Next, a target stimulus containing a set of very small concentric circles (approximating different sized pupils) was placed in the right eye piece of the mask so that it was picked up by the camera and displayed on the monitor. The image of the circles on the monitor was checked for any non-linearity due to the camera or optics and this was then corrected appropriately.

When an eye movement occurred the relationship between the four corneal reflections of the marker lights and the pupil-iris boundary altered. In the following sections the development of techniques to analyse this television picture are described.

5.8. DATA ANALYSIS

Eye movement studies give rise to a mass of data. The best way of coping with this is by using some form of computer analysis. The development of two techniques to convert the raw television picture data into a format suitable for such analysis is described in the next two sections. The first approach was developed from a pilot study. In this approach a technique for ascertaining the S's fixation location from the monitor together with any response is described and then the preparation of this data for its subsequent analysis elaborated. The alternate method was later developed in an attempt to speed up the analysis process.

5.9. THE FIRST TECHNIQUE

A pilot study was first carried out in which 5 Ss each fixated known points on three different calibration slides. Whilst fixating each point they depressed a response button. The video-taped record was replayed in slow motion and stopped whenever the appropriate response light came on. Using a sheet of clear acetate the pupil outline and marker light positions were traced from the screen of the monitor. Subsequent analysis of these acetate sheets indicated the possible use of first matching a grid pattern to the corneal reflections of the marker lights and then, by fitting a circle to the pupil, the resultant position of the pupil centre in terms of a grid reference could be inferred.

The pilot study gave an idea of the range of pupil sizes and variations encountered as seen on this size of monitor together with the range of possible grid sizes required. The following method of analysis was finally decided upon.

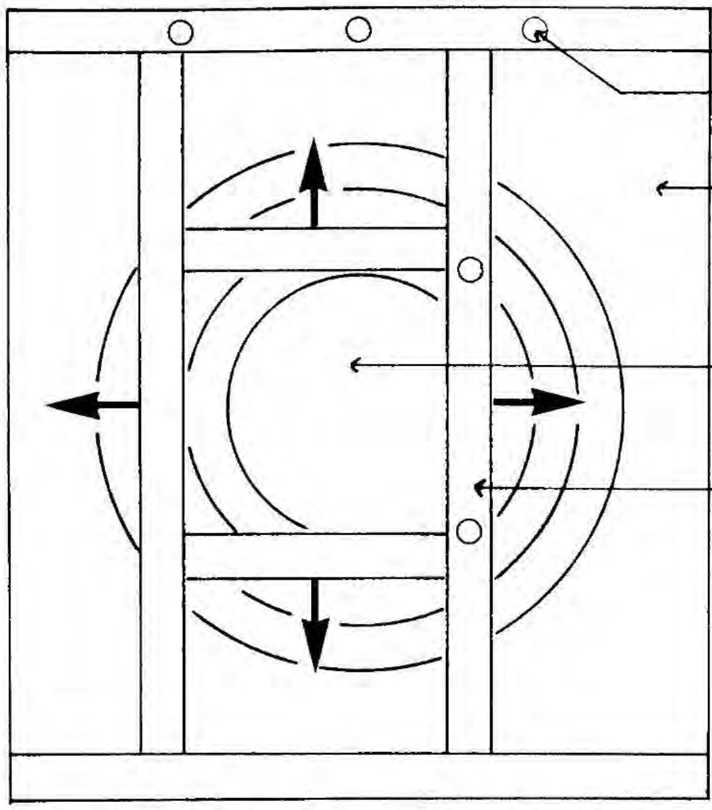
A large perspex sheet (PA) was fixed vertically over the screen of the television monitor to provide a flat working surface. A combination of three inter-related sheets of perspex were then utilised to find the pupil centre in terms of its relationship to the positions of the corneal reflections produced by the marker lights. This arrangement is shown in Figure 5.10 .

A clear perspex sheet (PB), 26.5. x 28.0 cms square had a series of 11 concentric circles deeply inscribed into both front and back surfaces from the same central position. The radii of these varied from 2.5 cms to 8.5 cms with 6 mm constant difference between them. A 1 mm diameter hole was drilled through the sheet at the centre of these circles and a light orange paper disc was mounted at its rear surface to aid its perception. Each circle was coloured differently in bright indelible ink using the same colour on each surface of the same radiused circle. Mounted on this sheet was a second rectangle of perspex (PC) which could be moved and held in a fixed position over the surface of PB by means of a third piece of perspex (PD) and various locking screws (see Figure 5.11). This combination moved smoothly over the vertical surface of PA with small pieces of felt preventing scratching of the perspex surfaces. This whole assembly of PB, PC and PD was suspended from the top of the monitor by an Anglepoise Lamp base which had been altered (removal of lamp head and elongation of springs) to provide a sprung counterbalance.

5.9.1. Pupil Centre Estimation

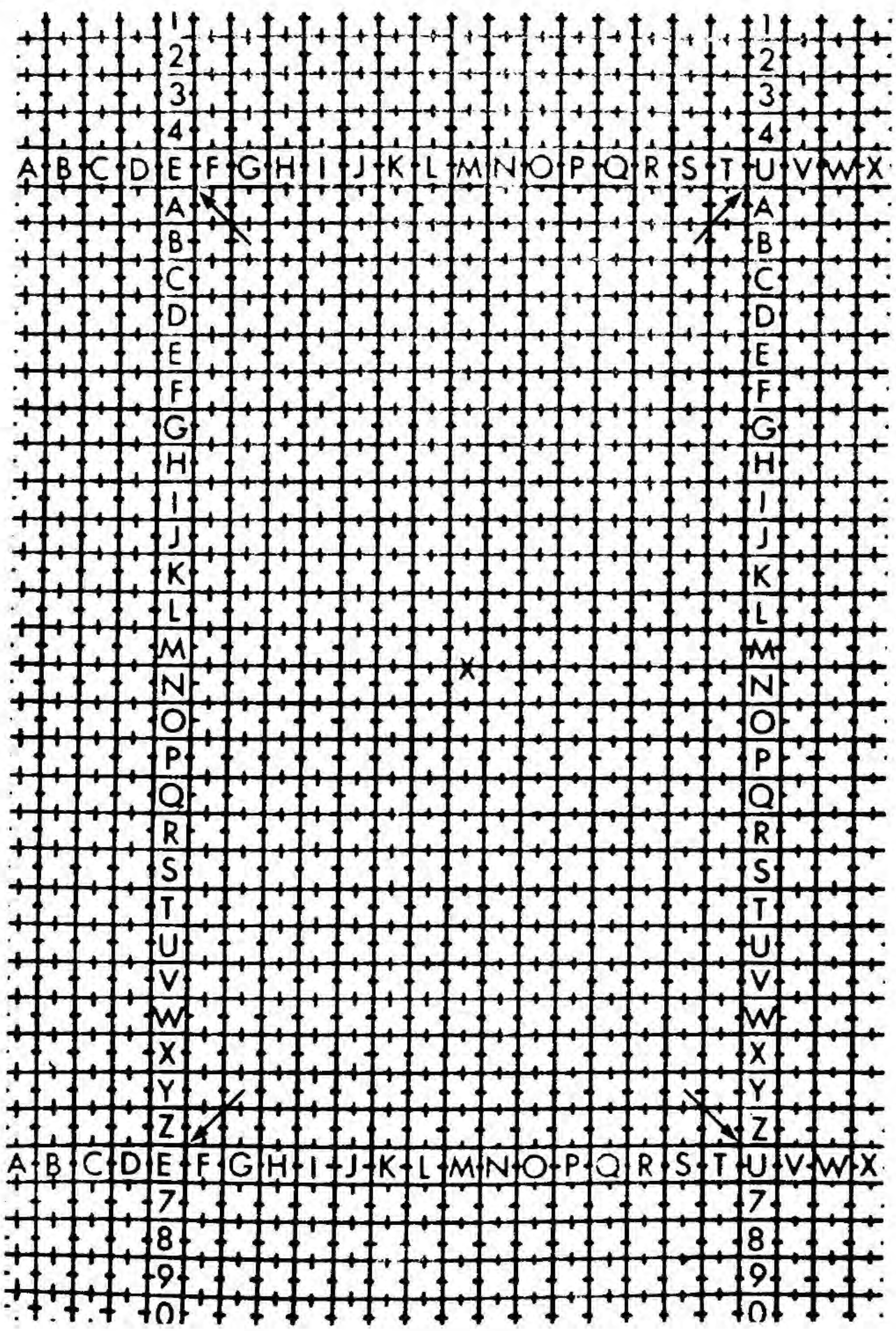
A reading was taken from the monitor in the following manner. The series of concentric circles were fitted to the pupil-iris border by a no-parallax manner using the dual concentric arrangement. The different coloured circles simplified this task and ensured no erroneous fitting by neighbouring circles.

The image of the pupil on the monitor became increasingly elliptical when viewed other than along the optic axis of the eye. When the recording axis of the camera coincided with the optic axis of the eye then the pupil appeared circular. As the elliptic appearance of the pupil



The arrows show the range of movements. PC moved vertically on sheet PD. PD moved horizontally on PB.

Figure 5.11 The arrangement of the perspex sheets.



The arrows indicate the position of holes that corresponded with the 4 marker lights' corneal reflections.

Figure 5.12 The analysis matrix.

became exaggerated owing to the difference between the optic axis and the viewing axis so the appropriate pupil circle was decided by the best fit to that part of the pupil nearest the centre of the monitor. The size of stimulus used ensured that this difference between the two axes was not too great so that the pupil seldom appeared very elliptical.

The different sized circles accounted for changes in the pupil size due both to actual pupil size changes and also to any slight alteration in magnification between subjects caused by using lens L_2 for focussing. Thus, the centre of the circles effectively gave the pupil centre.

5.9.2. The Corneal Reflections

The second perspex rectangle, PC, was in fact one of eight similarly sized sheets each 9 x 12 cms overall size. Each of these had a positive photographic transparency of a grid matrix attached to its surface. These eight matrices were each a slightly different magnification of the same negative, thus allowing for different image sizes of the corneal reflections of the marker lights. The matrix is shown in Figure 5.12 . Four small holes 1 mm in diameter were drilled through the matrix at the points indicated in the diagram. These points represented the positions of the marker light corneal reflections on the matrix.

Within the area bound by these four holes the matrix was divided into 15 (horizontally) x 26 (vertically) squares. The matrix extended outside this area to allow for peripheral fixations. Overall matrix size was 24 (horizontally) x 36 (vertically) squares with each square approximately subtending 1^{o} at the S's eye.

Each matrix square was identified by unique x and y co-ordinates. The horizontal co-ordinate range was A-X and the vertical range was 1-5, A-Z, 6-7. Positions 5 and 6 are not marked on the matrix as they would obliterate the horizontal lettering. This particular method of labelling the vertical axis was used so that a four figure alphanumeric co-ordinate reading specified any particular point. Each square was considered as divisible into 10 units, e.g. a point lying horizontally between G and H on the matrix could have its position read as G0, G1, G2....H0. The co-ordinate labels on the matrix refer to the dotted lines, the solid lines represent the central position between adjacent labels. Thus, the matrix centre marked 'X' in Figure 5.12 is given as M0 horizontally and M5 vertically.

The choice of suitable matrix size was accomplished by stopping the video tape at a suitable point before a stimulus presentation, when the S was known to be fixating a central point.

At this stage a small piece of perspex was offered up to the vertical perspex surface (PA). This small piece of perspex contained a series of pairs of small holes representing the horizontal distance between the marker light holes for each of the eight grid sizes. This range was from 3.2 cms to 4.6. cms with 2 mm constant difference between each adjacent matrix in the series. The appropriate grid was chosen by deciding which of these pair of holes best matched the horizontal distance between the image of the marker lights on the monitor.

Once the appropriate grid size had been determined in this manner then that particular grid was mounted up as sheet PC. This grid was then used for all measurements in the following stimulus presentation. Before the next stimulus presentation the appropriate grid size was again checked and so on. Usually, once a grid had been chosen, it was found appropriate for the analysis of the whole of that particular S's data. In practice, the vast majority of the data analysed in this manner utilised only 2-4 of the smaller sized grids.

5.9.3. Measurement of Fixation Location

To take a particular reading the whole perspex assembly was moved over the stopped television picture and the pupil centre found in the manner described above. Then, keeping the position of PB constant, PC was moved until the four holes were centrally positioned over the images of the four marker light reflections. This was achieved by a no-parallax fit of each hole to the corneal reflection of the marker light. The position of PB was then checked to ensure that it had not moved. The appropriate grid reading was then read by noting the position on the matrix of the centre of the hole representing the pupil centre. The orange disc behind this hole enhanced the ease of such readings against the television screen fluorescence.

The more peripheral a fixation became the more distorted were the marked light reflections on the eye. This took the form of a distortion of rectangularity of the four lights as well as distortion of a light spot into a spot and a 'tail'. These problems were overcome by making the initial grid match to that marker light (or lights) nearest the marked pupil centre as this would then have undergone the least distortion. The remaining marker lights were then matched. The other problem of elongated images of marker lights ('tails') was caused either by the image being formed on the non-linear surface of the cornea (which approximates a spherical section over its central 25^{o}) or from additional reflections caused by the tear film. In such cases the matching was made to the brightest point of the image of that corneal reflection on the monitor.

In general the time taken to make a reading once the video tape had been stopped was only a few seconds. Occasionally not all four marker lights would be present, e.g. the obscuring of a marker light reflection by an eyelash occasionally occurred

5.9.4. Data Recording

From the previous discussion of saccadic eye movements the maximum number expected to occur per second would be about 4. An analysis rate of .2s was chosen as it seemed reasonable to expect it to pick up each fixation without tediously analysing too many video frames. Other workers have used similar rates. Whiteside (1974) using video recording analysed a frame every 0.25s. With film recording Mackworth and Mackworth (1958) utilised a reading every .17s, Mackworth and Thomas(1962) used a rate of every 0.13s whereas Mackworth and Otto (1970) analysed a frame every 0.2s.

The actual method of scoring a particular television frame has been outlined earlier. The video recorder was set up to play back at a slow speed and at every tenth frame it was stopped and a reading taken. In addition to recording the co-ordinates of the pupil centre the following information, where appropriate, was also noted.

The number of television frames were counted since the previous reading. This figure was usually 10 frames. This was recorded and considered initially as the fixation time of the previous recorded fixation position. The fixation times are inevitably a multiple of the television frame rate. Due to the sampling procedure used a preponderance of fixation times of .2s ensued. This sampling rate became altered due to various occurrences:-

a) Blinks.

b) Inability to score the tenth frame, e.g. due to an ongoing saccade which would produce a very blurred image.

c) Where the S was making a response. A reading was taken the instant the image of the response light was noted on the monitor. Alternatively if the S had been indicating a response then a reading was taken when the brightness of the image of the response light began to fade, indicating cessation of that response.

In these cases after the appropriate reading had been taken the sampling reverted back to the original rate of analysis.

Blinks were recorded in the following manner. The onset of a blink was generally quite easy to detect as the video tape was being replayed at a slow analysis speed. It appeared on the screen as a sudden increase in contrast at the top of the picture caused by the reflection of the infra-red light by the descending upper lid. As soon as this was noted the video tape was stopped and a reading taken. The recorder was then restarted and as soon as the eyelid had again revealed an eye capable of measurement (usually when the upper lid was still just present on the screen) the next reading was taken. The time lapse between the two readings was taken as the time to make a blink.

In the experiment described in the next chapter each time a reading was taken the S's response state was noted. Six possible response states were characterised:-

a) NO - this refers to the 1s period of time before a stimulus had been presented, when a pre-stimulus fixation spot was present.

b) ST - refers to the first reading taken when the stimulus had been presented. This reading was always taken at the instant the counter was seen to initiate timing.

c) <u>YW</u> - when the S depressed the right hand-held response button so indicating 'young woman' perception of the ambiguous figure. This was taken when the appropriate response light was present on the monitor. All such readings were recorded in this way.

d) <u>OW</u> - when the subject pressed the left hand-held response button. This indicated the perceived aspect of the old woman in the ambiguous stimuli.

e) <u>NR</u> - a period of time when the stimulus was present but during which the subject made no response, i.e. no response lights were visible on the monitor.

In a typical analysis of an experimental run the following procedure would be used. First the instant the timer started counting, indicating the beginning of the stimulus presentation, was approximately located on the video recorder tape counter. After rewinding the tape a small distance it was then replayed at a slower rate until a short time before this. The video tape was then played at a very slow rate until the timer was seen to start counting when the recorder was switched to 'pause' and the tape rewound ten frames by hand.

At this stage it was assumed that the S was fixating a central fixation cross. The appropriate grid size was chosen and then a reading taken as described earlier. This reading was recorded as a NO state. The video tape was then run on until the timer was seen to change its .01s figure. Immediately a reading was taken and the state recorded as ST.

The recorded NO state served mainly to indicate on the plotted output where the S was fixating before the stimulus was presented. The rest of the experimental run was then analysed recording any responses or their absence (NR state) and any blinks.

Using a flexowriter a paper tape of this data was then manually prepared for subsequent computer analysis. This tape contained the following information:-

1) The date of the experiment.
2) The experiment number.
3) Subject code.
4) Stimulus code.
5) A value for a flag to indicate whether the data was for calibration or an

experimental run.

For experimental data the total number of inputs was then entered followed by a listing of the actual input co-ordinates, as read from the grid. Also noted were the number of frames between this and the following input and whether there was a blink or not immediately following this reading. For calibration data only the fixation location and the corresponding number of the fixated point on the calibration slide were noted.

5.10. ALTERNATIVE METHOD OF ANALYSIS

Although the time to take each reading in the previous method was only a few seconds this short period accumulated so that to analyse 10s of video recording took some 40-50 minutes. On top of this the data then had to be transposed onto paper tape to be fed into the computer for analysis.

In an attempt to speed up this process the following method was devised. Its advantages over the previous one are that it obviates the necessity of using the perspex assembly as well as not needing to translate the alphanumeric code from the television recording onto paper tape and thence via subsequent computer analysis into an X, Y real number co-ordinate. It could also provide an indication of pupil size which was not really possible with the previous approach, although this was not used in the experiment reported in the next chapter.

The apparatus is shown in figure 5.13 . A large oscilloscope (Lan Scope 419DD) was set at 90^{o} to a television monitor. Both had screens of approximately the same size and curvature, the monitor being selected for this particular reason. They were aligned so that the centre of their screens were at the same height. A large half silvered mirror was used by the experimenter to monocularly view both screens when using the chin rest as illustrated. The distance of the centre of each of the screens from the centre of the mirror was the same. In this way anything displayed on either screen would appear superimposed at the same distance upon the other.

The Department of Psychology's computer (IBM 1130) was used to drive the oscilloscope. Initially, this oscilloscope displayed an outline square and the oscilloscope controls were then checked to ensure that the X and Y magnifications were the same. The oscilloscope screen could thus be regarded as a linear matrix, 1024 points square. The video monitor had previously been checked for linearity as detailed for the previous method. The oscilloscope next displayed a small cross. By means of 8 response buttons this cross could be moved about by the experimenter and

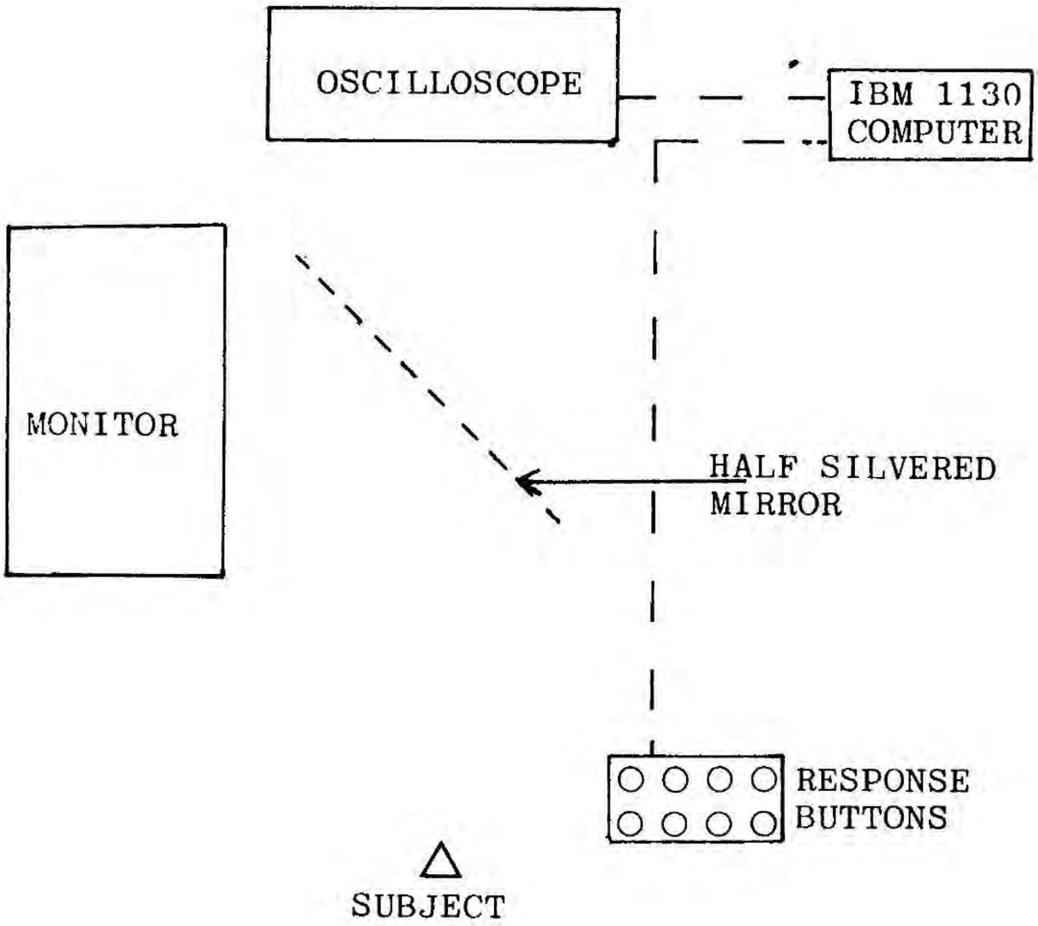


Figure 5.13 Diagram of the arrangement of the apparatus for the second analysis technique.

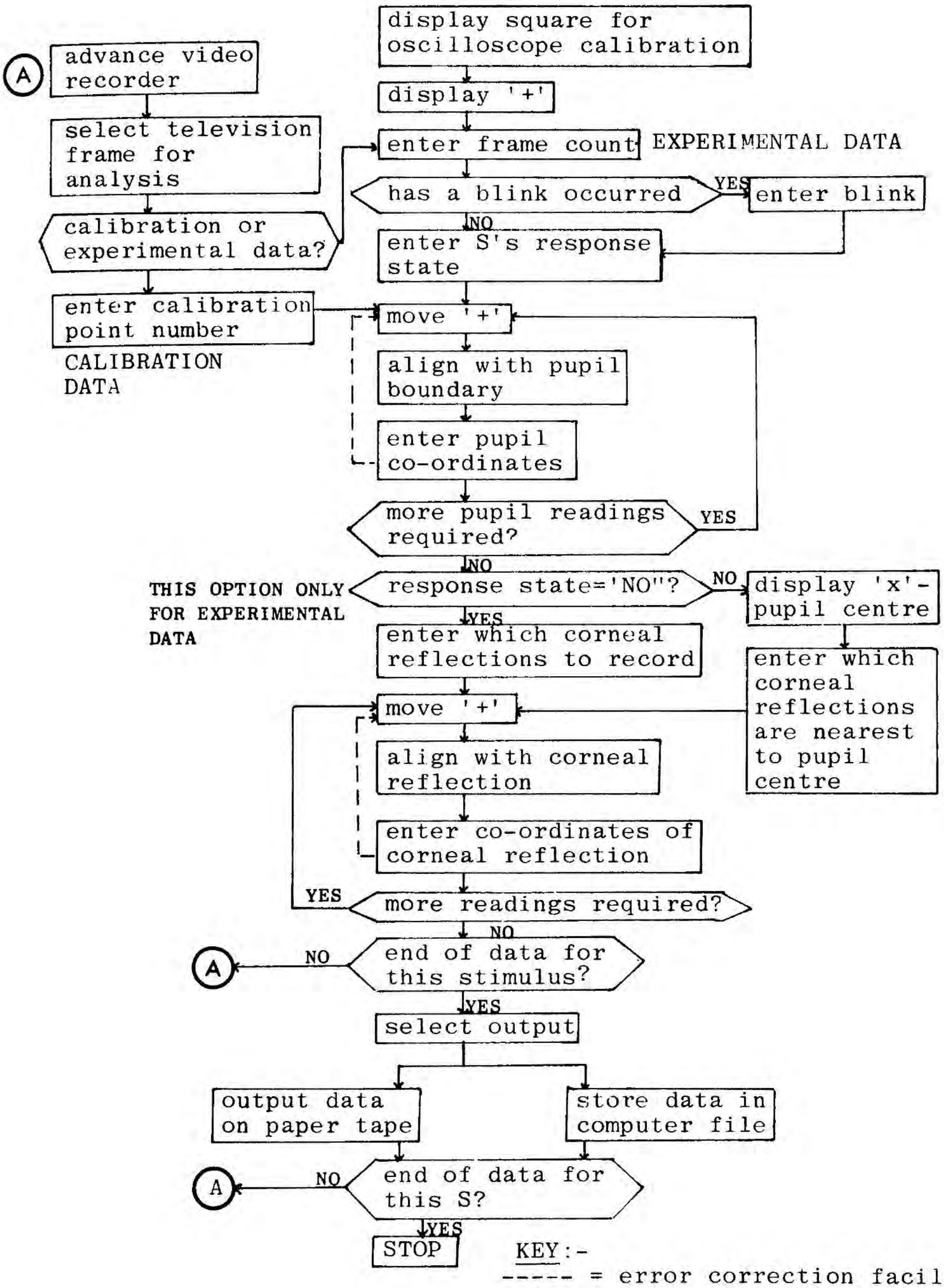
		CORRECTION CONSTANTS					
		HORIZONTAL			VERTICAL		
SUBJECT	TRIAL	A	B	C	E	F	G
A	1	0.706	0.023	1.624	0.028	0.732	4.668
	2	0.638	0.006	2.795	-0.018	0.733	4.501
B	1	0.746	0.017	2.656	-0.003	0.82	6.145
	2	0.747	0.013	2.695	-0.015	0.804	6.533
C	1	0.7	-0.001	2.809	0.005	0.72	6.441
	2	0.701	-0.005	3.123	0.006	0.704	6.677

Table 5.1 Values for the 6 correction constants obtained on the first and second calibration trial for each subject.

superimposed over points of interest (pupil-iris boundary, corneal reflections of marker lights) and the X, Y co-ordinate recorded. The same buttons served to enter the state, blinks and frame count. All this information was directly entered into a computer file for subsequent analysis or else a paper tape output of it was produced by the computer. This technique is next described and a flow chart of it is shown in Figure 5.14.

The buttons were illuminated under program control to provide feed-back to the experimenter of where he was in the sequence of data entry. Full correction of any erroneous entry was allowed for.

After advancing the video recorder to the appropriate television frame to be analysed, the frame count was entered, either in binary fashion, or by a series of single key presses as the video recorder slowly advanced. If a blink had occurred this was similarly noted by a key press. For experimental data the response state was next entered. The buttons were then used to move and superimpose the cross displayed on the oscilloscope over the pupil boundary on the monitor and four readings around this boundary were then taken. The cross was again moved and the co-ordinate positions of the marker light corneal reflections entered. Before entering these co-ordinates, four of the buttons were illuminated to indicate each of the



KEY:-
----- = error correction facility
enter = enter using the buttons
display = display on oscilloscope
move = move cross on oscilloscope by means of the buttons

Figure 5.14 Flow chart of the second analysis technique.

four corneal reflections. The experimenter pressed the appropriate buttons in the correct order in which he was then going to enter these co-ordinates. By this means if all four marker lights were not clearly evident on the monitor this could be accounted for.

When analysing experimental data (as opposed to calibration data) once the co-ordinates of points around the pupil had been entered then the oscilloscope also displayed a second cross indicating the centre of the pupil. For readings other than the initial 'NO' state reading then only the co-ordinates of the two corneal reflections of the marker lights nearest to this point were recorded. This, to some extent, allowed for distortions of the more peripheral corneal reflections. The 'NO' state readings of the four corneal reflections in this case were used to set up the 'rectangle' formed by the corneal reflections and used throughout the analysis of that trial to give the size of this rectangle.

For calibration data instead of first entering the frame count, blink occurrence and state response, the fixation point number was recorded in binary fashion. This was followed by pupil and corneal reflection readings as detailed above.

The output of this program for both calibration and experimental data was a numeric X, Y co-ordinate reading of the pupil centre with reference to the corneal reflections of the marker lights. For experimental data the frame count (fixation time) and blink occurrence were also recorded.

Data from an eye movement recording method utilising multiple light sources is difficult to analyse in any other way apart from a 'frame by frame' approach. Other approaches have similarly sought to speed up the scoring of each frame examined (Whiteside,1974 ; Haith,1969 ; Kundel and Nodine, 1973).

5.11. ERRORS OF THE EYE MOVEMENT RECORDING METHOD

Having detailed how the eye movement data displayed on the television monitor was transformed by two techniques into a suitable format for subsequent analysis it is first important to elaborate the errors of this method of recording eye movements. It is only by suitably correcting for such errors that a relatively accurate measure of fixation location can be obtained.

Point of regard methods which use the measurement of the pupil centre in relation to a corneal reflection of some light source are subject to various errors. These have been detailed by Slater and Findlay (1972a, 1975b) and by Bullinger (1974). Some discussion of the presence and magnitude of such errors with particular reference to neonates has occurred (Salapatek, Haith, Maurer and Kessen, 1972; Slater and Findlay, 1972b). There are two error sources, firstly the non-coincidence of the visual and optic axes of the eye and secondly the fact that the two elements of the eye (corneal reflection and observed pupil centre) do not quite lie in the same plane and thus give rise to parallax effects.

Considering the eye as an optical system one can distinguish 3 pupils: the true pupil, the exit pupil (the image of the true pupil formed by the lens of the eye, and the entrance pupil (Bennett and Francis,1962). The entrance pupil is the magnified image of the true pupil formed by refraction at the cornea. In point of regard eye movement techniques it is to this entrance pupil to which measurements are referenced (Bullinger, 1974).

The estimation of the location of the corneal reflection of a distant object by reference to the centre of this entrance pupil is in reality determining the point on the object lying on the pupillary axis (this is a line perpendicular to the cornea through the centre of the entrance pupil). Whereas the S will actually be fixating a point on the object lying on the visual axis. This axis being in essence a line joining the fovea to the object, in reality it is composed of 2 parallel lines passing through the 2 nodal points of the eye. The visual axis and the pupillary axis do not coincide and so the estimation of the point of regard of the S will be in error.

The discrepancy between these 2 axes is some 4-5^{o} temporal and just greater than 1^{o} vertically (Bennett and Francis, 1962). This effect is equal and opposite in both eyes so that for binocular viewing of an object the 2 eyes deviate horizontally by some 10^{o} (Slater and Findlay, 1975b). The horizontal angle between the pupillary and visual axes is known as the angle kappa. The pupillary axis can be considered as being synonymous with the optic axis of the eye. Thus angle kappa is equivalent to angle alpha, the latter being the angle between the optic and visual axes (Slater and Findlay, 1975b).

The entrance pupil of the adult human lies some 3.05 mm (Bennett and Francis, 1962) behind the corneal surface. The corneal reflex of a distant object unfortunately does not lie in quite the same plane as this. Instead it is some 3.9 mm behind the corneal surface. Thus, when the S's eye is viewed from a point which is not on the S's line of sight, a parallax error will occur in estimating the direction of the S's gaze. The virtual image (corneal reflex) of an object fixated by the S lies at the principal focus of the eye. For off-axis observation this point will be judged relative to the entrance pupil such that for a 20^{o} off-axis horizontal observation position an apparent displacement of 4.4^{o} visual angle will occur between the corneal reflex and the centre of the entrance pupil (Slater and Findlay, 1975b).

The measured position of the S's direction of regard will thus be either 9.4^{o} or 0.4^{o} horizontally displaced when both of the previous errors are corrected.

For large angular discrepancies between the fixated target and the observation axis there will be a further error due to corneal spherical aberration such that the virtual image of the target instead of being located at the principal focus will be located nearer the plane of the entrance pupil. Also the pupil itself may not dilate around a fixed centre thus the estimated position of the pupil centre may vary with pupil diameter which will also introduce an additional error.

5.12. ERROR CORRECTION

Slater and Findlay (1975b), in describing the various errors of recording eye movements by this approach, present data which demonstrates that the deviation of the measured fixation position from the actual position fixated increases as the angular difference between the fixation position of the S and the observation axis of the S's eye increases. This deviation approximates a straight line function between $\mp 20^{o}$ visual angle of this difference. Although not explored by Slater and Findlay this demonstrates that, to a first order, a correction for these errors can be applied by a 'least squares' technique.

The following correction procedure was subsequently devised. With the S fixating a series of points on a calibration slide, measures of fixation position as well as the true position of the point being fixated were obtained. These were then used to generate appropriate correction constants which were both applied to this raw calibration data, to give an estimated fixation position, as well as subsequently applied to other data of the eye movements of the same S when looking at different stimuli.

The corrections were calculated in the following manner. If the measured horizontal and vertical co-ordinates of a fixation are x and y with the corresponding real co-ordinates of the fixated point being z and t. Then the calculated co-ordinate position of the fixation is given by:-

$$z^{1} = Ax + By + C$$

$$t^{1} = Dx + Ey + F$$

where z^{1} is the horizontal and t^{1} the vertical calculated positions. A, B, C, D, E and F are constants which can then be calculated. The derivation of these constants is given in Appendix D. A computer program was written to calculate these constants and provide a paper tape output of them which was subsequently taken to correct other data for this subject. The program also printed out the measured fixation positions, the true positions fixated and the estimated fixation positions. Plots of these are shown in the next section. The estimated fixation position was the corrected mean position for each calibration point of both of the measured positions.

5.13. EVALUATION TRIAL

The following trial was carried out to ascertain the accuracy of the technique.

5.13.1 Subjects

Three Ss were used who were familiar with the apparatus.

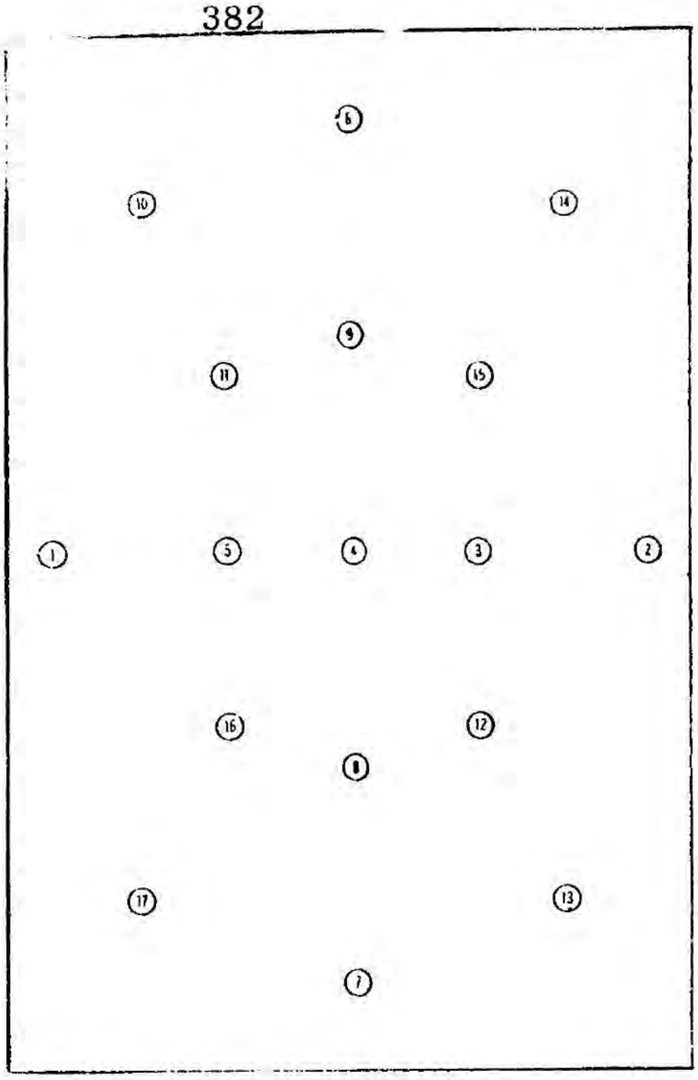
5.13.2 Stimuli

Three stimulus slides were used as shown in Figure 5.15. These were:

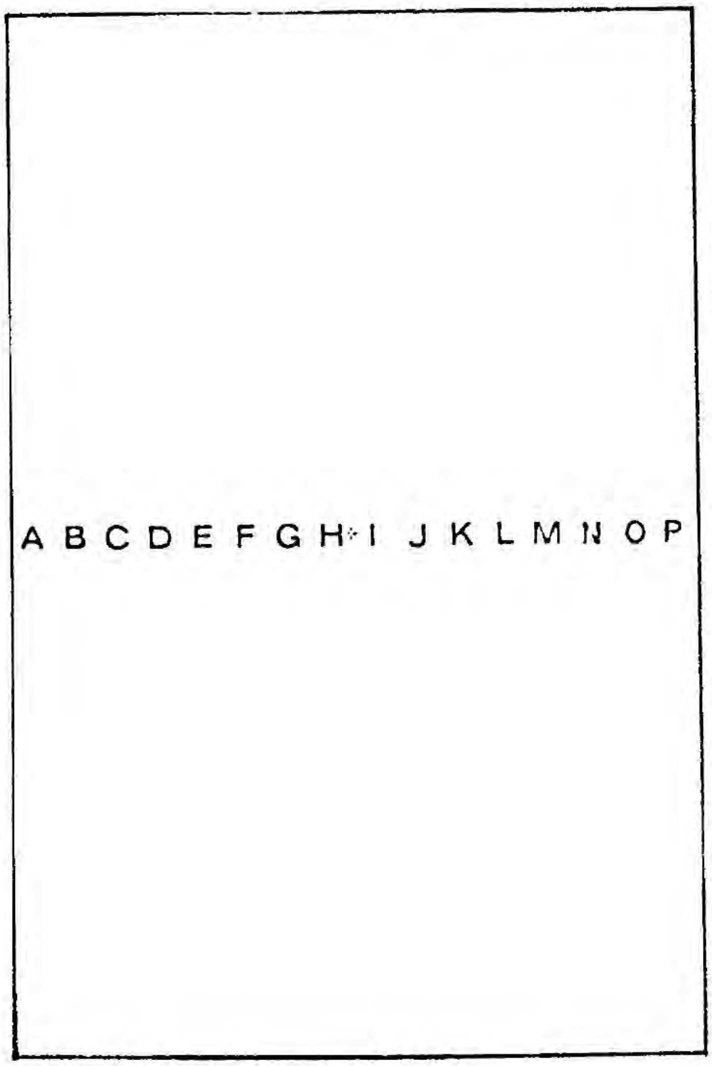
a. A 17 point calibration display.

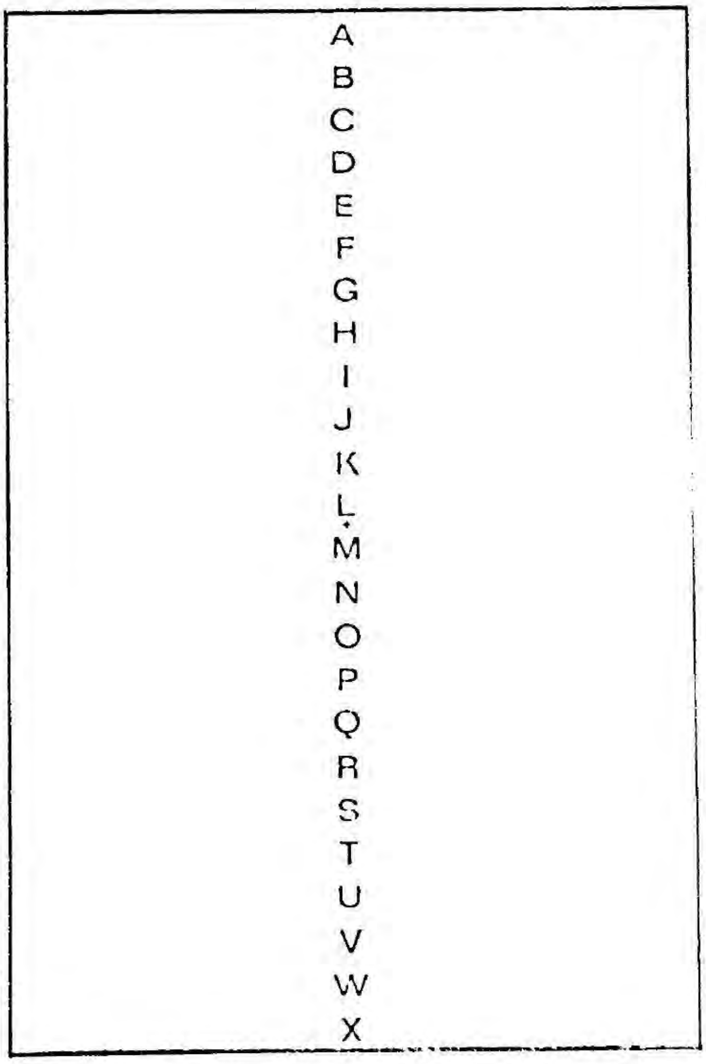
b. A vertical column of 24 letters constructed so that the centre to centre distance between each letter subtended 1^{o} at the S's eye.

c. A horizontal row of 16 letters arranged in a



CALIBRATION STIMULUS





HORIZONTAL STIMULUS

VERTICAL STIMULUS

Figure 5.15 The 3 stimuli.

similar fashion to the vertical display.

Each of these slides had been projected onto graph paper to enable the co-ordinates of each fixation point , as projected, to be recorded.

5.13.3. <u>Procedure</u>

Each S was first presented with the 17 point calibration slide. They were instructed to sequentially fixate the centre of each of the numbered circles. As they fixated each one they pressed and briefly held down one of the response buttons and then released it before going on to fixate the next number. The experimenter slowly counted between 1 and 17 and the Ss fixated the points at this rate.

The horizontal and vertical arrays were then presented, with similar instructions to fixate the centre of each letter and to press the response button as they did so. Again the experimenter called out each letter in turn. Finally the 17 point calibration display was again presented . The eye movements of each S were recorded as they did this.

5.13.4. <u>Analysis and Results</u>

The video tape was analysed by the first technique described earlier so as to obtain the co-ordinates of each fixation position. For the calibration slides 2 readings of each fixation position on the display were taken as soon as the response light indicating a fixation appeared on the monitor and within 4 television frames of one another. This was to attempt to pick up the same fixation. A difference in scored position should then reflect both the ability to re-measure the same fixation plus the error introduced by miniature eye movements during the fixation.

These measures of the S's fixation positions on the calibration slide were then used to generate the horizontal and vertical correction constants as detailed in the previous section. Plots of each S's measured fixation location and the computed mean fixation location for each calibration point are shown in Figures 5.16-5.18. In these plots the 2 measures of the S's fixation location for each point together with the computed mean position are shown joined by lines to each of the numbered calibration points. The overall error between the computed mean locations and the actual calibration points is also given for each S.

In addition each plot shows graphs of the horizontal and vertical disparity between the actual positions fixated and the measured positions of the S's fixation location. In the graph showing the vertical disparity between real and measured fixation positions the vertical co-ordinates of the 17 point calibration stimulus are plotted on the horizontal axis between 'UP' and 'DN'(down). Thus calibration

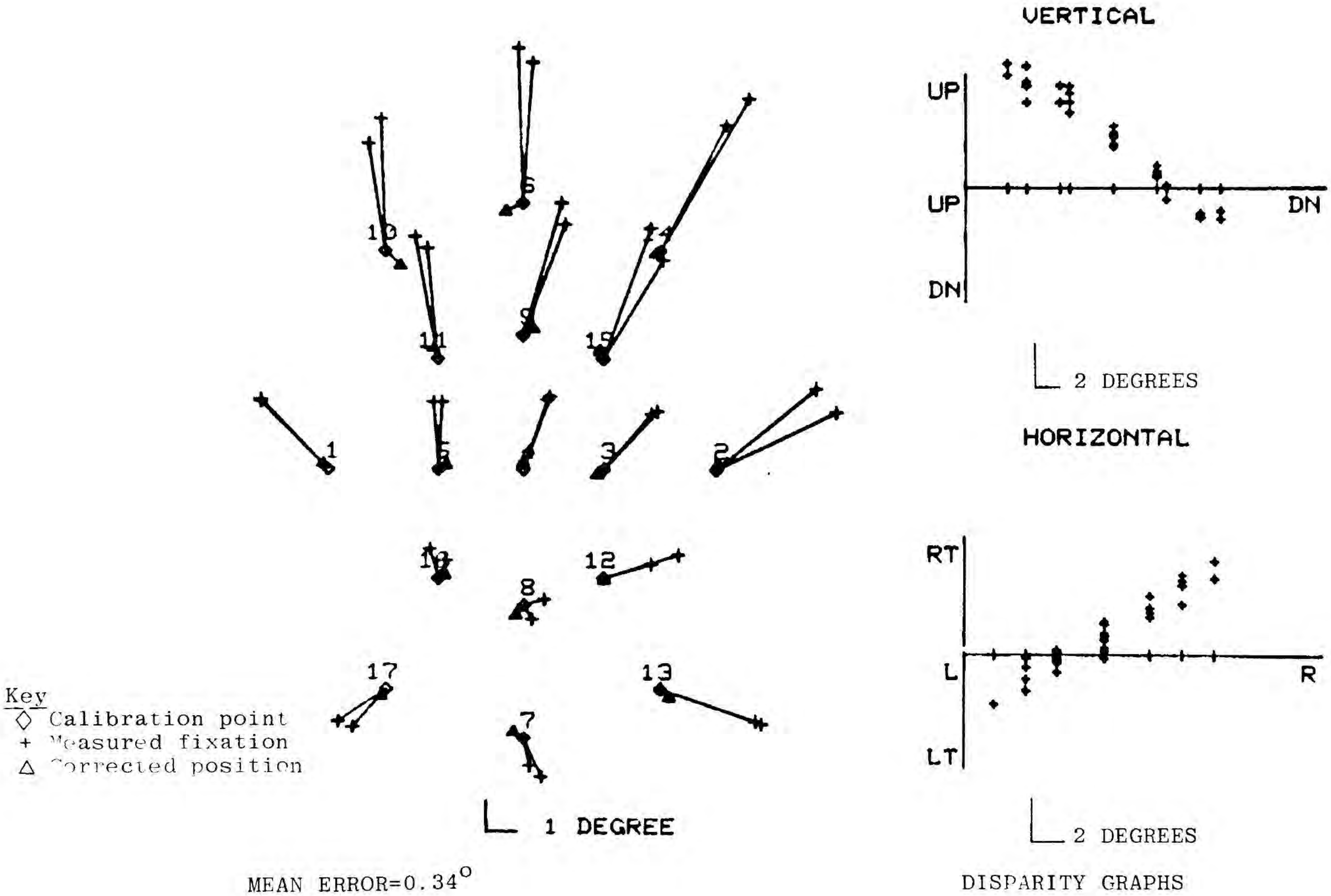


Figure 5.16 Calibration data and disparity graphs for subject A.

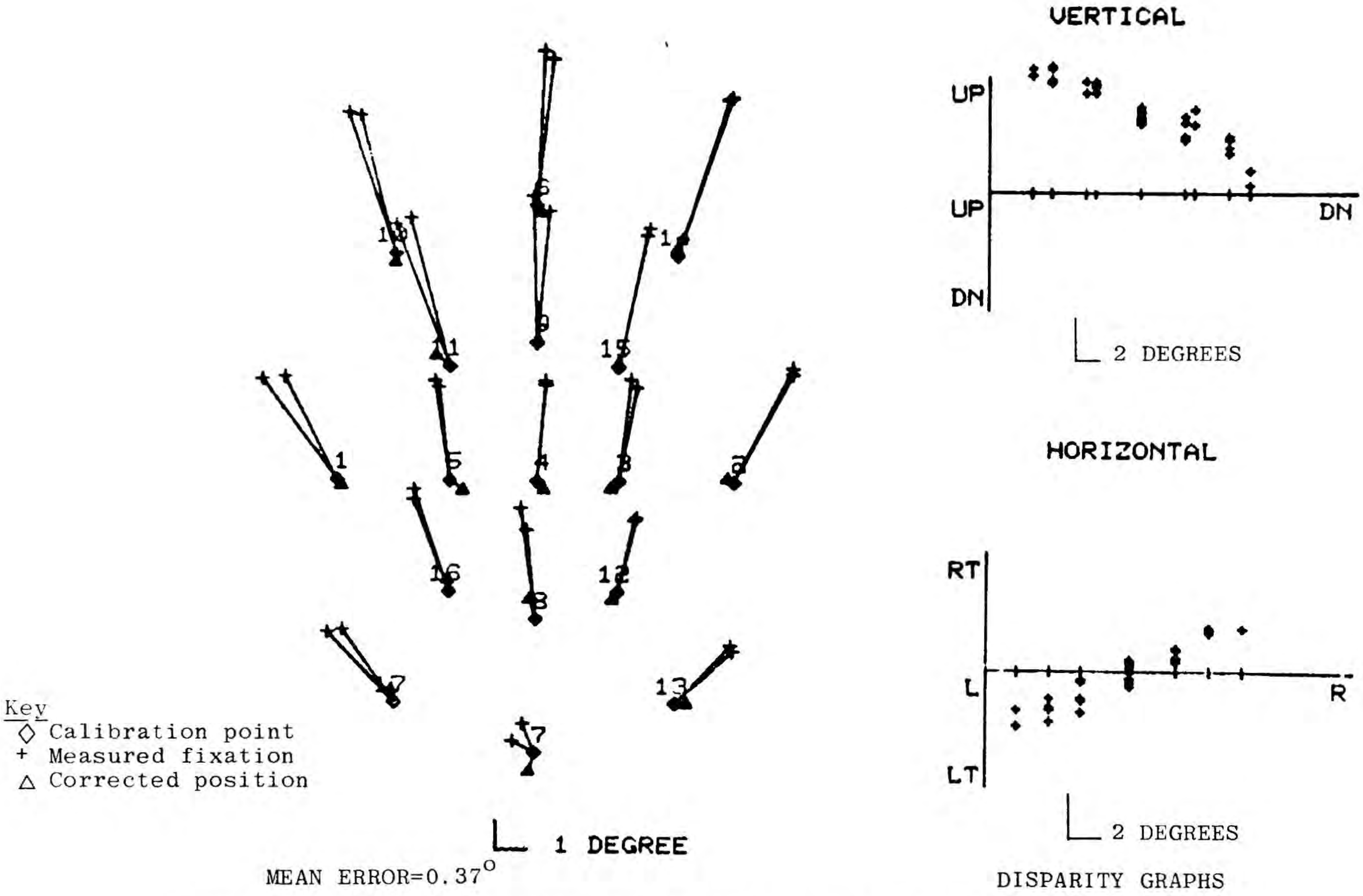
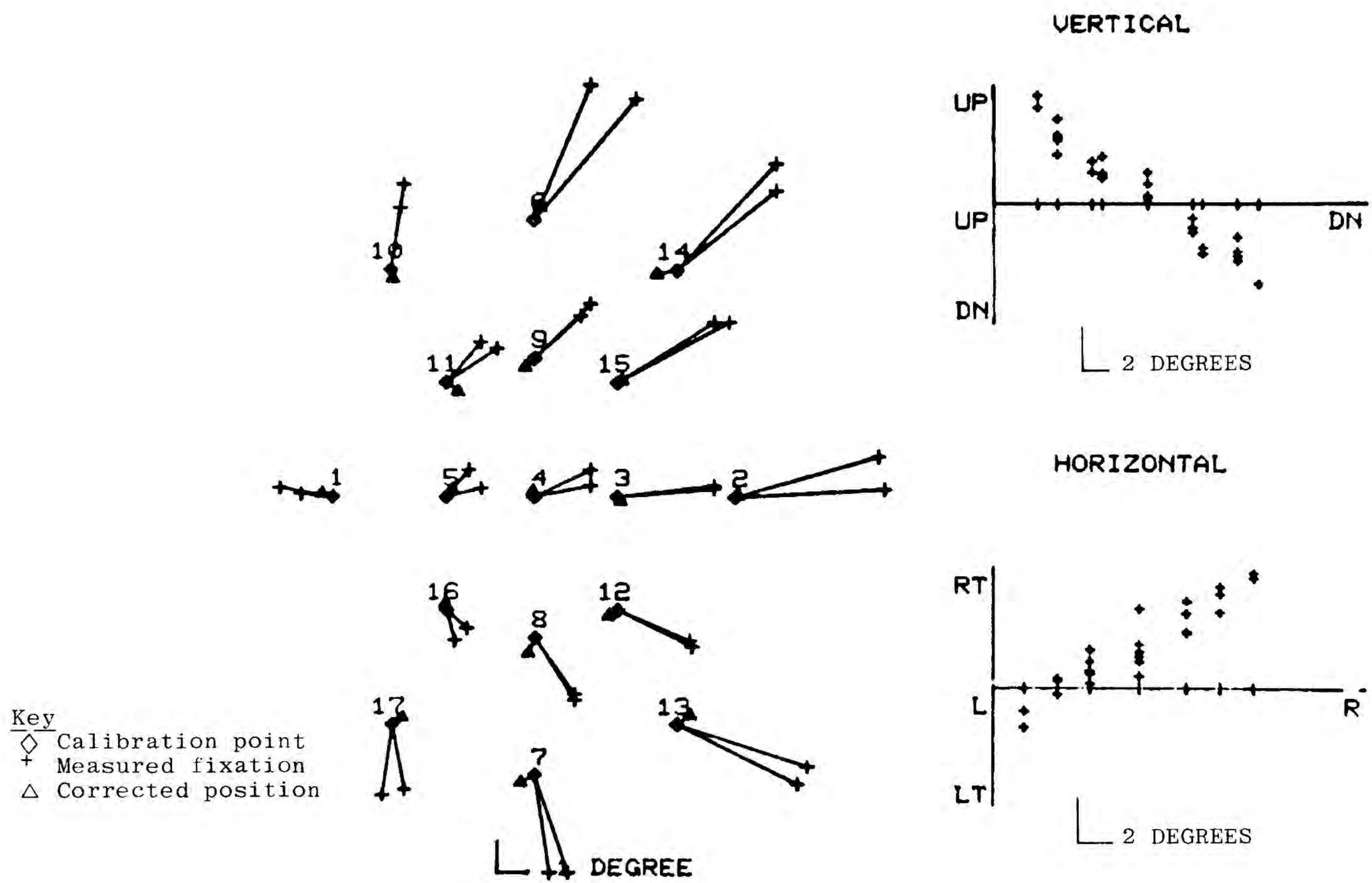


Figure 5.17 Calibration data and disparity graphs for subject B.



MEAN ERROR=0.38°

DISPARITY GRAPHS

Figure 5.18 Calibration data and disparity graphs for subject C.

point 6 is represented as the left-most tick on this axis and 7 is the right-most tick. The disparity between the measured fixation locations and each of these true positions is shown on the vertical axis depending whether the measured position was either higher('UP') or lower ('DN') than the actual calibration point e.g. the two fixation positions for point 6 are the first 2 data points on the left of the graph.

Similarly the graph of the horizontal disparity shows as its horizontal axis the horizontal position of each calibration point running from left(L) to right(R) of the stimulus so that the left-most point is calibration position 1. The disparity between the measured positions and each calibration point is then shown on the vertical axis as a deviation to the right (R) or the left (L) of this real point.

For all Ss both the horizontal and vertical disparity graphs show essentially a straight line deviation between real and measured fixation location thus confirming Slater and Findlay's(1975b) results. For each S the mean calculated fixation position was within 0.4° of the actual position fixated.

The values obtained for the horizontal and vertical correction constants from the analysis of the calibration data were then used to correct that S's fixation positions for the horizontal and vertical arrays. This is shown in Figures 5.19 and 5.20. The mean error for all Ss between

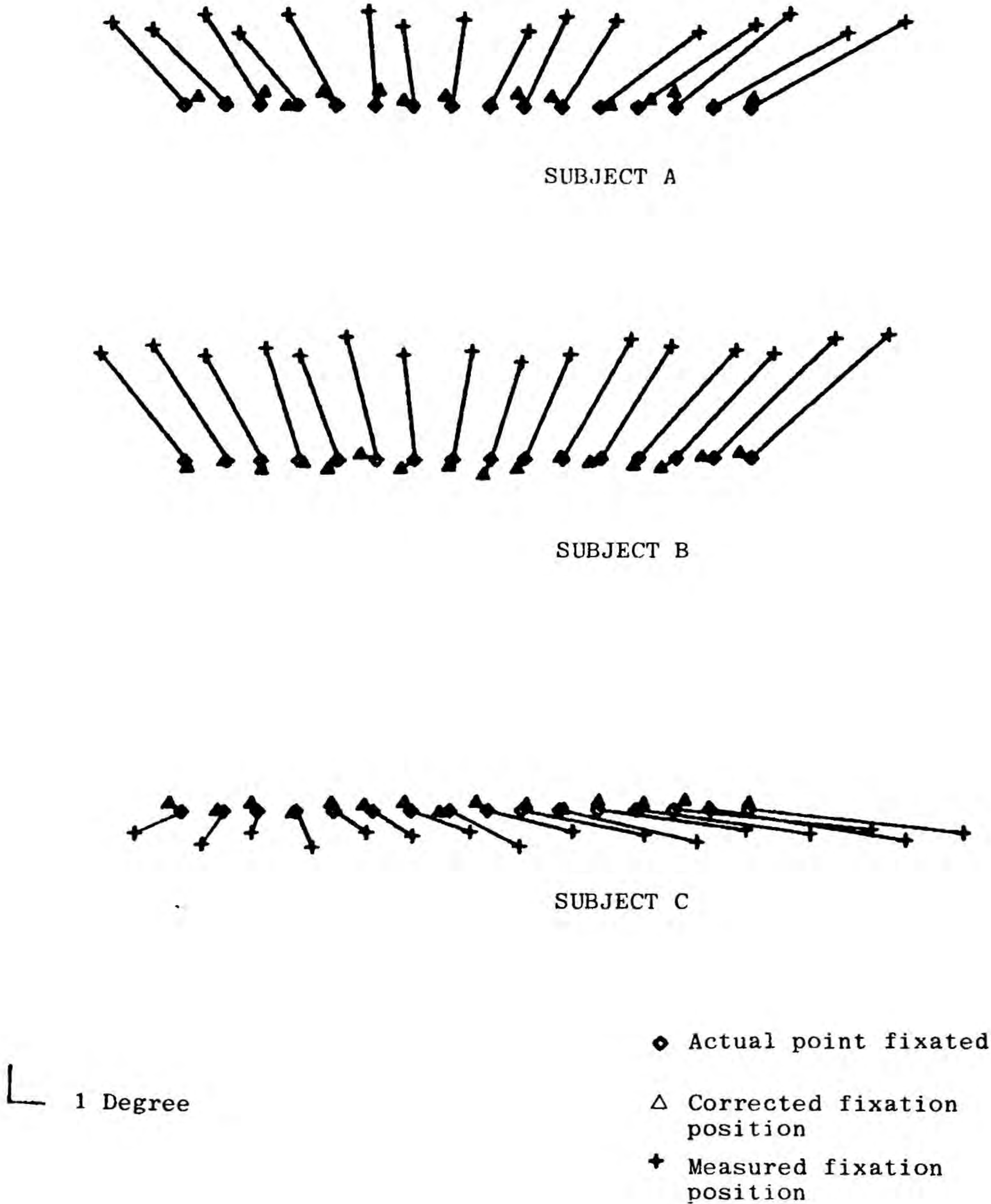


Figure 5.19 Data for all 3 subjects fixating the horizontal stimulus.

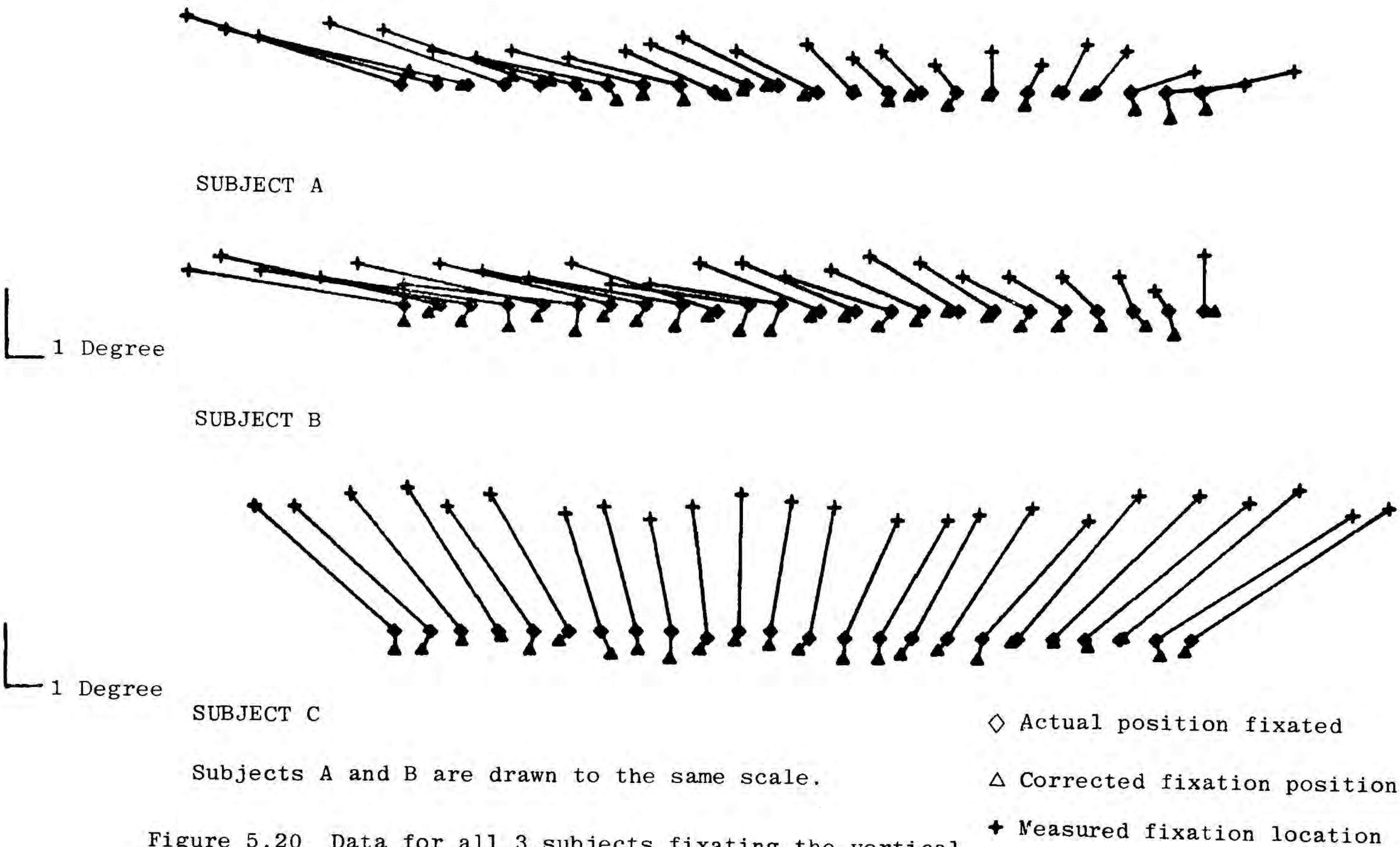


Figure 5.20 Data for all 3 subjects fixating the vertical stimulus.

the calculated fixation position and the actual target letter position on these arrays was some 0.3^{o}.

The second trial on the 17 point calibration slide produced similar results to the first trial, these are shown in Appendix E . Again the overall mean difference for all Ss between the real and calculated fixation positions was some 0.5^{o}. The similarity in the values obtained for the correction constants for each S on the first and second presentations of the calibration slide is shown in Table 5.1 .

These results indicate that with this technique a S could be presented with a series of stimulus slides and then afterwards be shown the calibration slide, the data of which could be used to suitably correct the previous experimental trials with an accuracy of some 0.5^{o}.

5.14. OUTLINE OF THE COMPUTER PROGRAMS

The television display of the S's eye movements could be analysed by either using the perspex grids or by the on-line method described earlier. The output of both approaches was a paper tape containing the co-ordinates of each fixation location, the fixation time (expressed as a number of television frames), the S's response and blink occurrence. The on-line method also permitted direct entry of this data onto a computer data file.

The calibration data was used in one computer program to generate the appropriate correction constants as detailed in section 5.12 which were then output on paper tape and subsequently used to correct the experimental data for that S. A flow chart of the main analysis and plotting program is shown in Figure 5.21. This program was used to generate the data plots shown in the next chapter and it is now briefly described.

All the co-ordinates of the S's fixation positions during an experimental trial were first corrected using the calibration constants. The experimenter could then decide in what manner to study the data of each trial. The various options were:-

(A) A print-out of the fixation locations, fixation times and saccade lengths. This was used to obtain the total values of these variables for each stimulus.

(B) The fixation density. This calculated the number of fixations falling in each 1° square of the stimulus display by considering it as a matrix of 24 x 16 squares.

(C) The eye movements could be plotted out in various formats each with or without a superimposed stimulus facsimile. To further correct for possible re-measuring of the same fixation, the data could be 'reduced' by combining sequential fixations falling within 0.5° of each other.

Each sequential fixation position could be

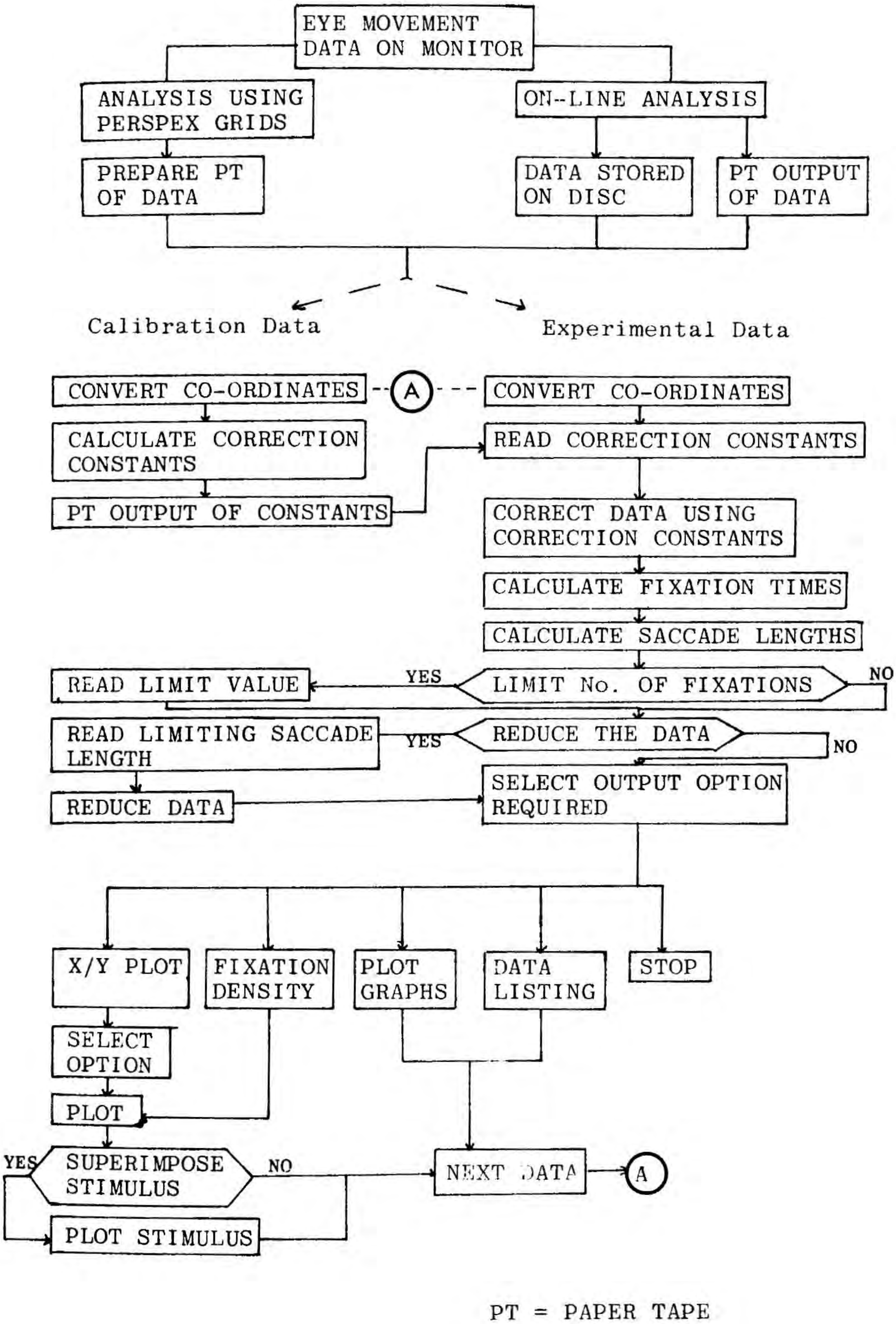


Figure 5.21 Flow chart of the analysis program.

plotted out joined by an arrow (to indicate a saccade) or a dotted line representing a blink. This was used to illustrate the overall visual scanning of the S and could also be done with the sequential numbering of the fixations. The response of the S at each fixation location could be represented by a different symbol (e.g. Figure 6.7) and arrows used to indicate the scanning pattern when a change in response occurred (as shown in Appendix F). Instead of plotting all the S's eye movements, a limit (n) could be selected and only the first n fixations plotted. This was used to ascertain the first fixation position when the S responded- as shown circled in Appendix F.

The data was first plotted out for examination on an oscilloscope display and then later, on a suitable plotter.

5.15. SUMMARY

After describing the different types of eye movements the techniques developed to record these movements were considered. A suitable method was selected which would allow recording of a S's saccadic eye movements without his knowledge. This was then detailed together with appropriate methods of analysing, correcting and plotting out the data. In the next chapter an experiment using this technique with the ambiguous figure is described.

C H A P T E R 6

THE EYE MOVEMENT EXPERIMENT

6.1. INTRODUCTION

The experiments reported in the previous chapters supported the hypothesis that the response to the line drawing of the ambiguous figure was largely determined by which elements were available to the S. The availability of the elements refers both to which elements were present in the stimulus and also to which elements the S could attend to when his fixation position was controlled. These elements it was argued were differentially weighted towards each aspect. The S's response to the stimulus was proposed to be a result of the sum of the weightings of those elements to which he could attend. The free viewing experiments demonstrated that the presence or absence of these elements in the stimulus display affected the response to the stimulus in a similar fashion to the afterimage situations where the S's fixation location upon the display was predetermined.

The afterimage studies demonstrated that the perception of figure in the stimulus was determined both by fixation location as well as by which elements were available to the S at that location. This implies that selective visual attention is important in the perception of the stimulus. In a normal viewing situation eye movements would occur which would shift the locus of attention about the stimulus in a somewhat similar manner to the use of the different fixation positions with the afterimage approach. These studies demonstrated the importance of the M element in determining OW perception and the free viewing experiments further elaborated the influence of the YE element in eliciting YW perception. Findings of interactions between elements or between elements and fixation position were interpreted as showing that para - foveally and foveally viewed parts of the stimulus were influential in determining the response.

Neither of these experimental approachesprovided any information about how the S scans such a stimulus in a free viewing situation or about what happens when fluctuations occur. The interest has so far been in examining the distribution of the 'bias' or element weightings over the stimulus when it was first presented.

Experimental studies of eye movements in the perception of fluctuating figures were reviewed in Chapter 2 and the conclusion was reached that a situation was required in which the S would be unaware of his eye movements being recorded. The last chapter detailed the construction of suitable equipment to achieve this. In the present chapter an experiment is described in which Ss' eye movements were recorded as they viewed the line drawing of the ambiguous figure. It was also argued in Chapter 2 that a stimulus should be of sufficient size to permit both aspects to be seen whilst at the same time allowing selective attention to only part of the stimulus display. In this manner it would be possible to examine how different stimulus areas affect the perception of the figure. The afterimage studies demonstrated that this was possible with a stimulus some 36^{o} x 28^{o} visual angle in size. The free viewing experiments used slightly smaller stimuli with similar results.

It was hypothesised that given that Ss could perceive both aspects in the stimulus then if they were instructed to see this stimulus as the YW aspect their eye movements would be concentrated towards the YE element. Furthermore if they were instructed to perceive the OW aspect then their eye movements would be more concentrated towards the M element. The actual eye movements it was predicted would be somewhat individualistic but two relatively distinct patterns of fixation locations were hypothesised to occur. This was based on the afterimage experiments which demonstrated that a fixation near the YE element elicited more YW responses from Ss and a similar point near the M element elicited more OW responses.

In normal viewing of the ambiguous figure for a period of time fluctuations occur. In the present experiment Ss viewed the stimulus for some 10s. It was hypothesised that as the perception of the stimulus altered (fluctuation occurred) so too would the S's fixation location. Thus, as the S was responding 'YW aspect' to the stimulus it was hypothesised that he would fixate towards the YE element and as he responded 'OW' he would fixate more towards the M element.

Two further questions were of interest. What happens when the elements are then removed from the stimulus and the S fluctuates between the two aspects? Also, does an eye movement necessarily precede a fluctuation in a causal manner as many researchers have investigated? With regard to the first question it was hypothesised that altering elements should affect the first response obtained in a similar fashion to that found in the previous experiments. Absence of the M element should, on the basis of the previous results, produce a YW response first and also absence of the YE element should first produce an OW response. It is more difficult to predict an effect of the absence of the other two elements except that their absence should favour the YW aspect more. In a situation where one or more elements are absent the interesting question can be asked of where does the S fixate when he is responding as each aspect? For example, if as shown by the previous experiments the YE element largely determines a YW response and so when the S is responding as this aspect he is predicted to look towards this element. Then in the absence of this element does he fixate in the same region of the stimulus or does he fixate elsewhere when making this response? One of the functions of the schematic map as detailed in Chapter 1 is to 'tell' the S what to expect at a particular location. If the map is of importance then it was hypothesised that the S will tend to fixate in the same regions as when the elements were present. If, however, the concept of the schematic map is incorrect then the S's fixation location would primarily be determined by the physical parameters of the particular stimulus he is viewing, i.e. he will fixate towards other parts of the stimulus.

To answer the second question concerning fluctuation. It was proposed in Chapter 2 that fluctuations occur due to attention lapses, some of which will involve re-interpreting an already fixated point in the display and some of which will involve eye movements and fixations with no expectation of interpreting the elements of the stimulus as one particular aspect. Thus, it was hypothesised that eye movements would sometimes be related to reversals (the latter case) and at other times not. However, once the stimulus was re-interpreted as the alternative aspect then eye movements were hypothesised to occur to particular regions of the stimulus which strongly favoured the new aspect.

6.2. EXPERIMENT 6

6.2.1. Subjects

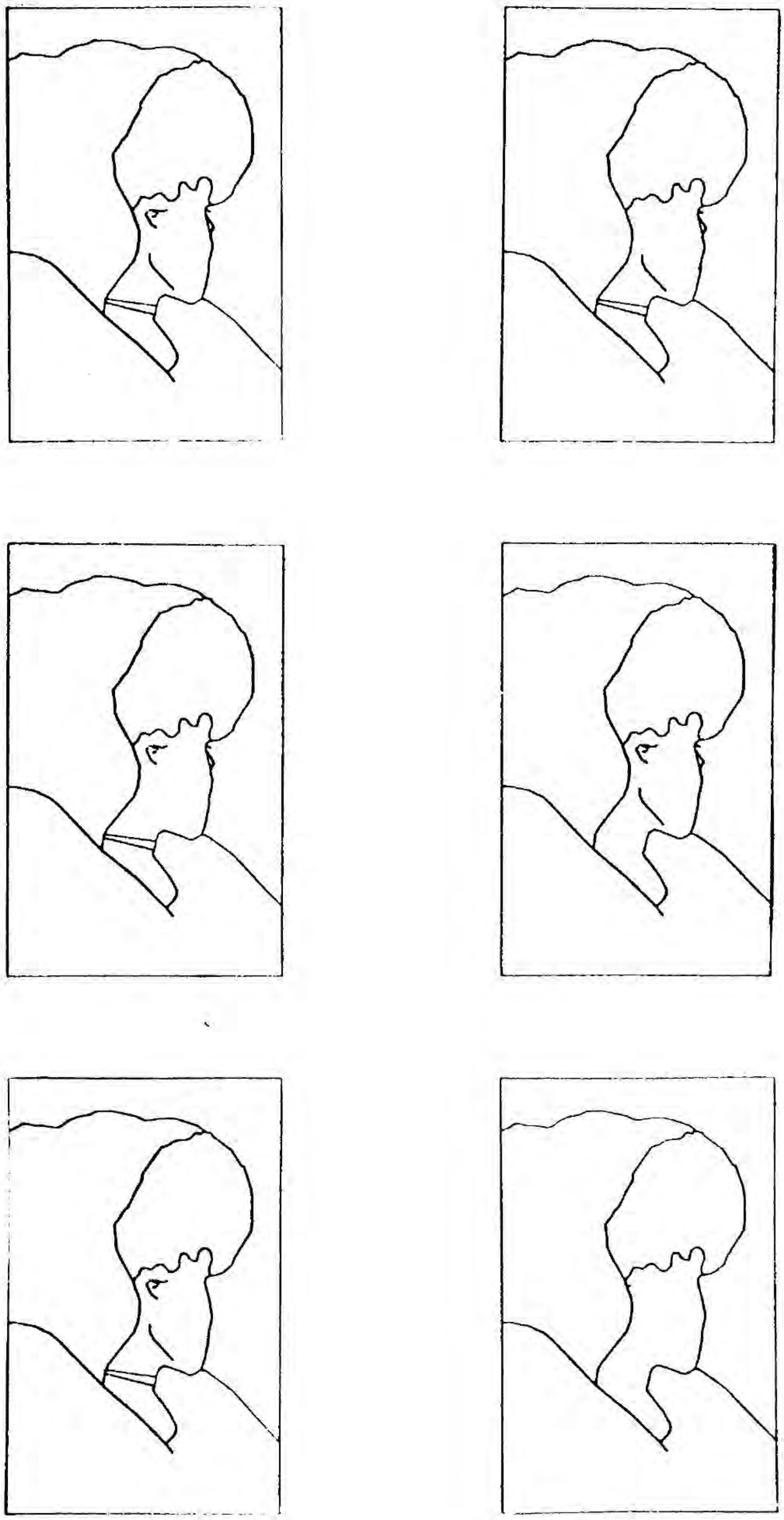
Six undergraduate Ss took part in the experiment. Data from 5 of these only is considered here as the video tape recording of the eye movements of the other S could not be analysed due to a camera problem which had produced a distorted image of the eye. All Ss were run individually and had volunteered to take part in an experiment on visual perception in which they had to look at some slides.

6.2.2. Apparatus

The apparatus was described in the previous chapter.

6.2.3. Stimuli

Seven stimuli were presented to Ss as rear projected 35 mm slides. All stimuli were black line drawings. One of these was of the face used by Noton and Stark (1971a),the others were versions of the ambiguous line drawing used in the previous



<u>Figure 6.1</u> The 6 different stimulus versions.

experiments. The six versions were: the full ambiguous figure, 4 other versions each with one of the 4 elements omitted, and a version with all of the 4 elements omitted. These are shown in Figure 6.1 . The calibration slide described in the previous chapter was also used. The projected slides subtended $24^o \times 16^o$ at the S's eye.

6.2.4. Procedure

The apparatus described in the previous chapter was so arranged that when Ss entered the experimental room they saw only the front of the viewing box. The other equipment being hidden by a screen. Once the S was seated at the viewing box it was impossible for him to see the television monitor or other apparatus.

When the S entered the experimental room he was shown the viewing box and told that it was a type of tachistoscope in which slides would be projected onto the back of the box and all he had to do was to sit with his chin on the chin rest and look at the slides through the goggles. The infra-red LEDs mounted in the right eye piece of the goggles were pointed out to the S as 'small lights' left over from another experiment which had nothing to do with the present one.

Ss were instructed:

> "There are several parts to the experiment. The first part simply involves you looking at some slides which you will see projected onto the screen. First though I want to make sure the chin rest is at a comfortable height for you."

The subject was then seated and the chin rest adjusted to a comfortable height. With the S then sitting in position the experimenter moved the screen so that he could view the television monitor which displayed the image of the S's right eye. The height of the chin rest was then altered until the image of this eye was central on the screen. The impression given to the S during this was that the alteration was for his own comfort. The S was then told to sit back from the goggles and was then instructed:

> "I am going to show you a sequence of slides. All I want you to do is to simply look at them. What will happen is this. Firstly, the screen at the back of the box will be illuminated with diffuse light and then a central fixation cross will appear. I want you to fixate the cross and then after a second or so this will be replaced with the stimulus which you can freely look at. After several seconds the stimulus will disappear and you will be presented with the blank field, then the fixation cross and then the next stimulus .... and so on. O.K. Do you have any questions?" ....."I have to operate the projector from behind the box."

The S then sat in position and the experimenter started both the slide sequence and the video recorder. The first stimulus was the 'face' stimulus from Noton and Stark (1971a) and the second one was the full ambiguous line drawing of Boring's figure, facing left or right. Both were shown for 10s. The slide duration was manually timed by watching the timer display on the monitor and terminating each slide by operating switch S_2. The recorder was then stopped and the experimenter walked round to the S and asked him to sit back from the goggles and describe the last stimulus.

A photograph of Boring's ambiguous figure was then shown to the S and he was asked to both describe it and whether he had seen it before. Both aspects were then verbally described to the S, as in the previous experiments, and the S told that the last stimulus was a line drawing of this photograph. S was allowed a few minutes to look at the photograph and practice alternating between the two aspects. The following instructions were then given:

> "Now I am going to show you the last slide again, this will be shown in the same fashion as before with an initial fixation cross. When the stimulus slide appears I want you to concentrate solely on viewing the picture as a young woman. After a few seconds the stimulus will disappear and after a similar interval it will reappear when I want you to concentrate on viewing it as an old woman. O.K. Do you have any questions?" ..."So this time I want you to concentrate on the young woman."

The full line drawing stimulus was then shown for 10s. During the interstimulus interval the experimenter repeated:

> "O.K. now this second time I want you to concentrate on the old woman."

Half the Ss were instructed to first look at the old and then the young woman.

The S was then shown the two push buttons which S then held, one in each hand.

> "Now I am going to show you the same slide again but this time I want you to just freely look at it. When it appears to you to be the YW I want you to press and hold down the right hand button. Hold it down all the time it looks like the YW. When it looks like the OW press and hold down the left hand button all the time it looks like the OW. When it looks like neither don't press either button."

S was then allowed to practice pressing and holding down each button whilst viewing the photograph. When he was familiar with the response procedure he was then instructed:

> "O.K. now what I am going to do is to present you with a series of line drawings similar to the one you have just been looking at. All I want you to do is to press and hold down the right button when it looks like the YW and press and hold down the left button when it looks like the OW. Do this for each slide. Any questions?"

The different versions of the line drawings of Boring's figure were either presented in a right or a left facing manner, this being randomly chosen for each S, except that the first stimulus was always the full drawing facing in the same direction as the S had just seen. All stimuli were presented for 10s.

After viewing these stimuli the S was shown the calibration slide and asked to fixate the centre of each numbered circle in turn and to press the right hand button as he did so.

At the end of the experiment the S was asked if he had any idea what the experiment involved.

6.2.5. Results

Data analysis. The eye movements of the 5 Ss were analysed for each experimental condition using both of the previously described scoring methods.

Readings were generally taken of every 10^{th} television frame except when the S blinked or altered his response. As soon as one of the response lights appeared on the monitor the video recorder was stopped and a reading taken. Similarly as soon as an existing response light present on the monitor began to dim a reading of fixation position was taken. These readings of the beginning or end of a S's response were then corrected for the lag inherent in the combination of the camera lag for a bright light and also the rise time of the response lights. This combined delay was some 2 television frames (0.04s).

The analysis program then reduced this corrected data by taking a weighted mean of any sequential fixations falling within $\mp 0.5^{o}$ of one another. This was to partly correct for the accuracy of the technique where an error of this magnitude may represent a measurement of the same fixation position. This procedure did not apply to any fixation involving a change of response state or a blink.

The stimulus slides had previously been projected on to graph paper and from this co-ordinates were taken of the outline stimulus which were then used in the plotting program to produce a facsimile with the fixation positions superimposed.

The eye movements obtained in the first 4 experimental conditions are shown plotted as arrows joining each sequential fixation position. A dotted line indicates the eye movement occurring during a blink.

For the stimulus conditions involving the ambiguous line drawing the number of fixations on or near each of the 4 elements was calculated. First the analysis program estimated the fixation density per degree, considering the stimulus as a matrix (24 x 16 squares) and summing the number of fixations occurring in each square.

No element was encompassed by a single square in this manner and so a number of squares around each element were taken to represent a fixation on or near that particular element which allowed for errors of measurement. This was done so that in general a fixation falling within 1.5^0 of any part of one of the elements was included and where every 'element area' was represented by an equal number of such squares (9) as shown in Figure 6,2. The number of fixations per 'element area' is shown for each S in the graphs accompanying each of the data plots where it is expressed as a percentage of the total number of

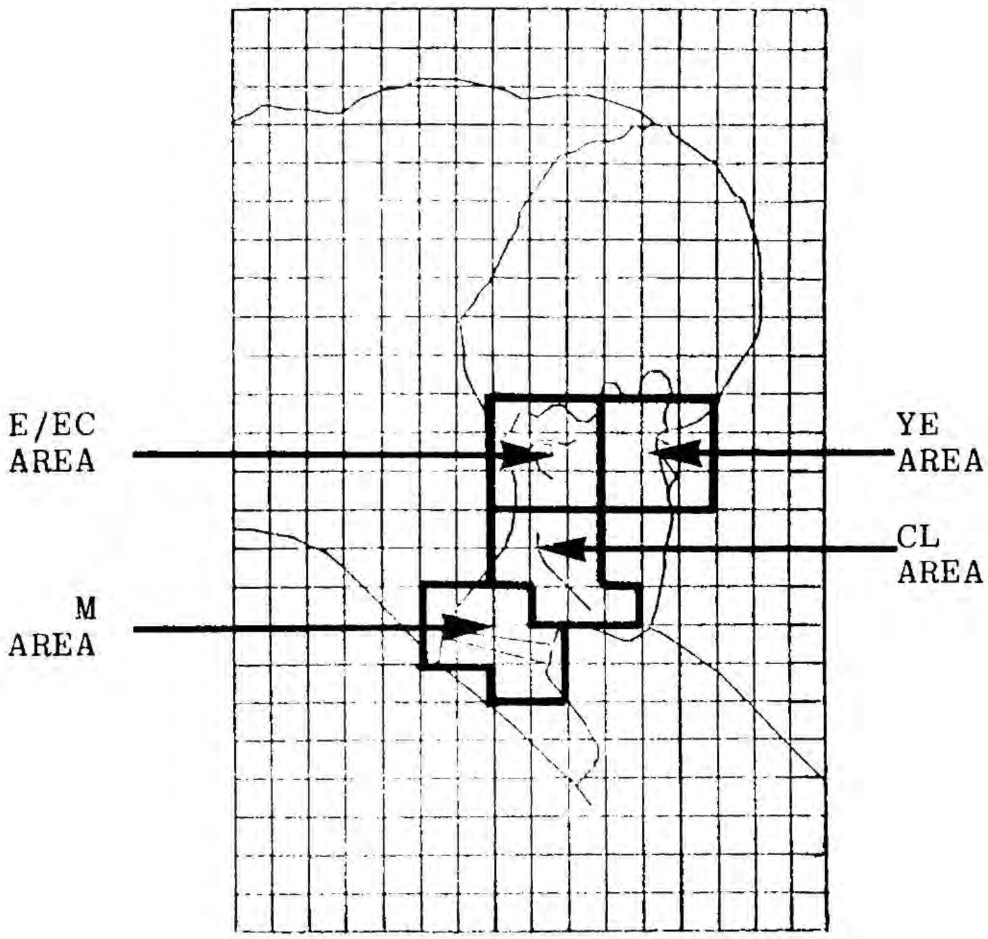


Figure 6.2 The stimulus divided into the matrix of 1^{o} squares showing the 4 'element areas'.

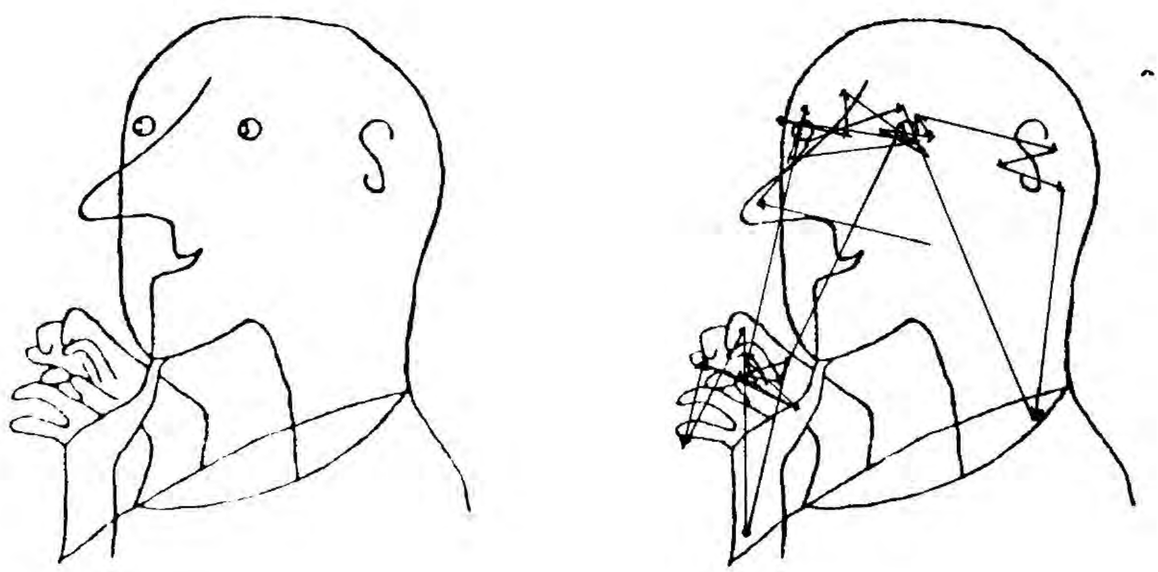


Figure 6.3 The face stimulus and the pattern of eye movements of subject SW when presented with it.

fixations on that stimulus. The overall percentage of fixations made by each S in all 4 'element areas' is given above each graph.

Noton and Stark stimulus. A typical example of a pattern of eye movements found for this stimulus is shown in Figure 6.3 . Fixations tended to be at informative points in the outline.

Naive presentation of the ambiguous figure.

Figure 6.4(a) shows the pattern of eye movements of each S upon first presentation of this stimulus. The patterns demonstrate concentration upon the facial area of the stimulus. Four of the Ss scanned the 4 elements of the ambiguous figure with most fixations concentrating upon the E/EC and YE elements. One subject (AS) concentrated exclusively on the E/EC element with some movement towards the YE element. This is shown in the accompanying graphs (Figure6.4(b)) where all Ss made most fixations in an area encompassing the E/EC element with the YE element area being the next most often fixated.

Young woman aspect. When asked to concentrate upon the YW aspect the scanning patterns obtained are shown in Figure 6.5(a). Compared to the previous condition the fixations were limited to the upper part of the face, concentrating on the YE element or both the YE and E/EC elements. Two Ss only concentrated on these 2 elements or points in between. 2 other Ss (PS and SW) also encompassed the CL element but, again, showed a concentration

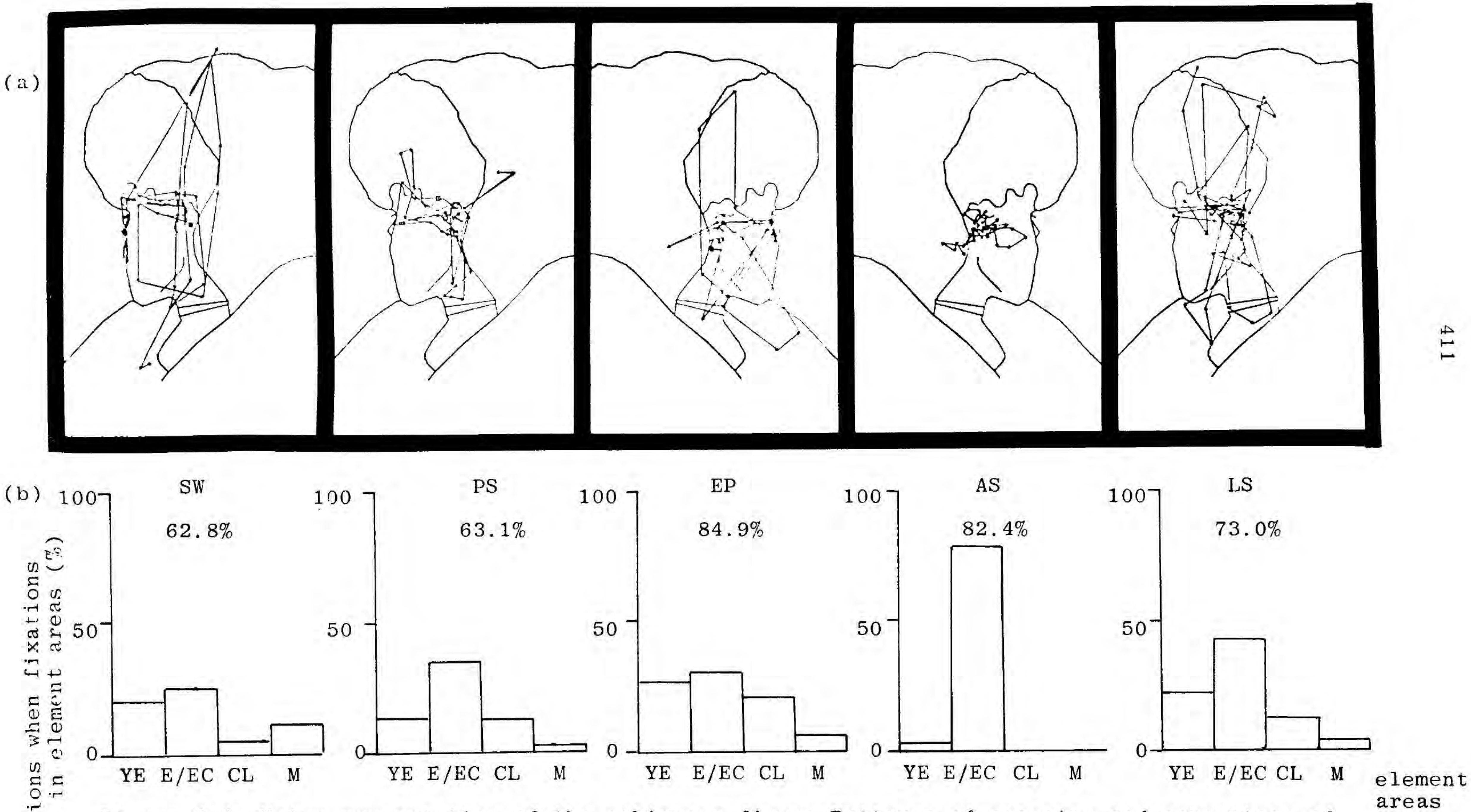
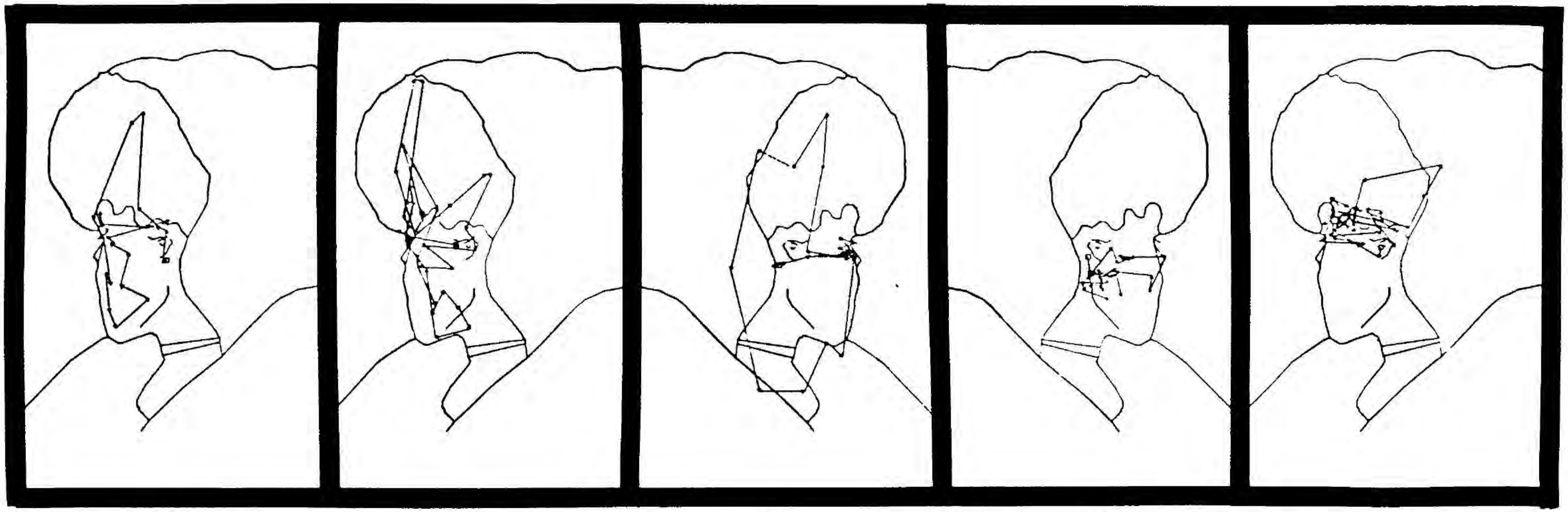


Figure 6.4 Naive presentation of the ambiguous figure. Patterns of scanning and percentage of fixations in each element area for the 5 subjects.

(a)



(b)

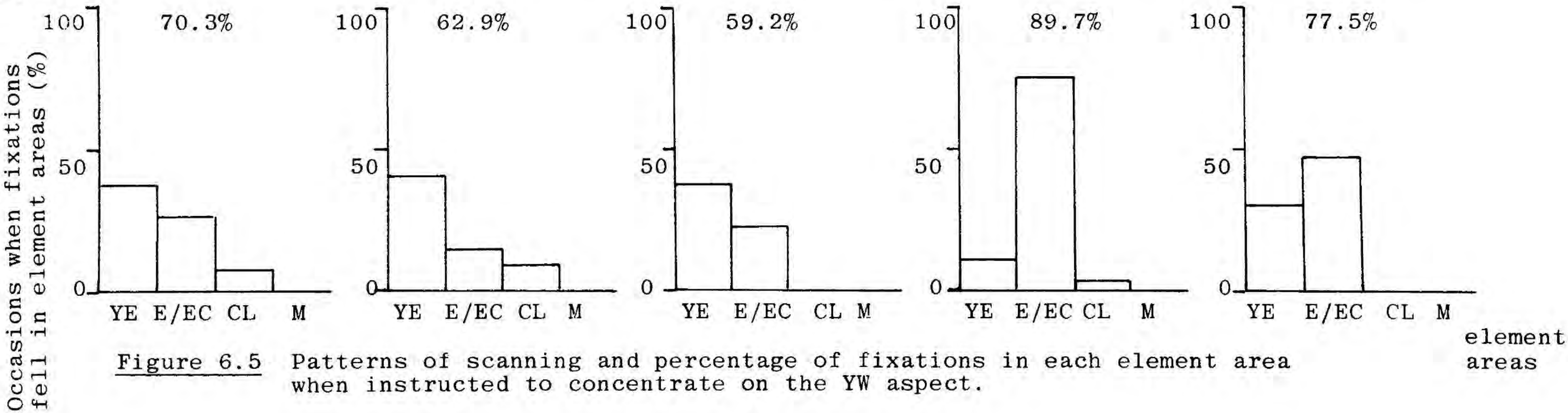
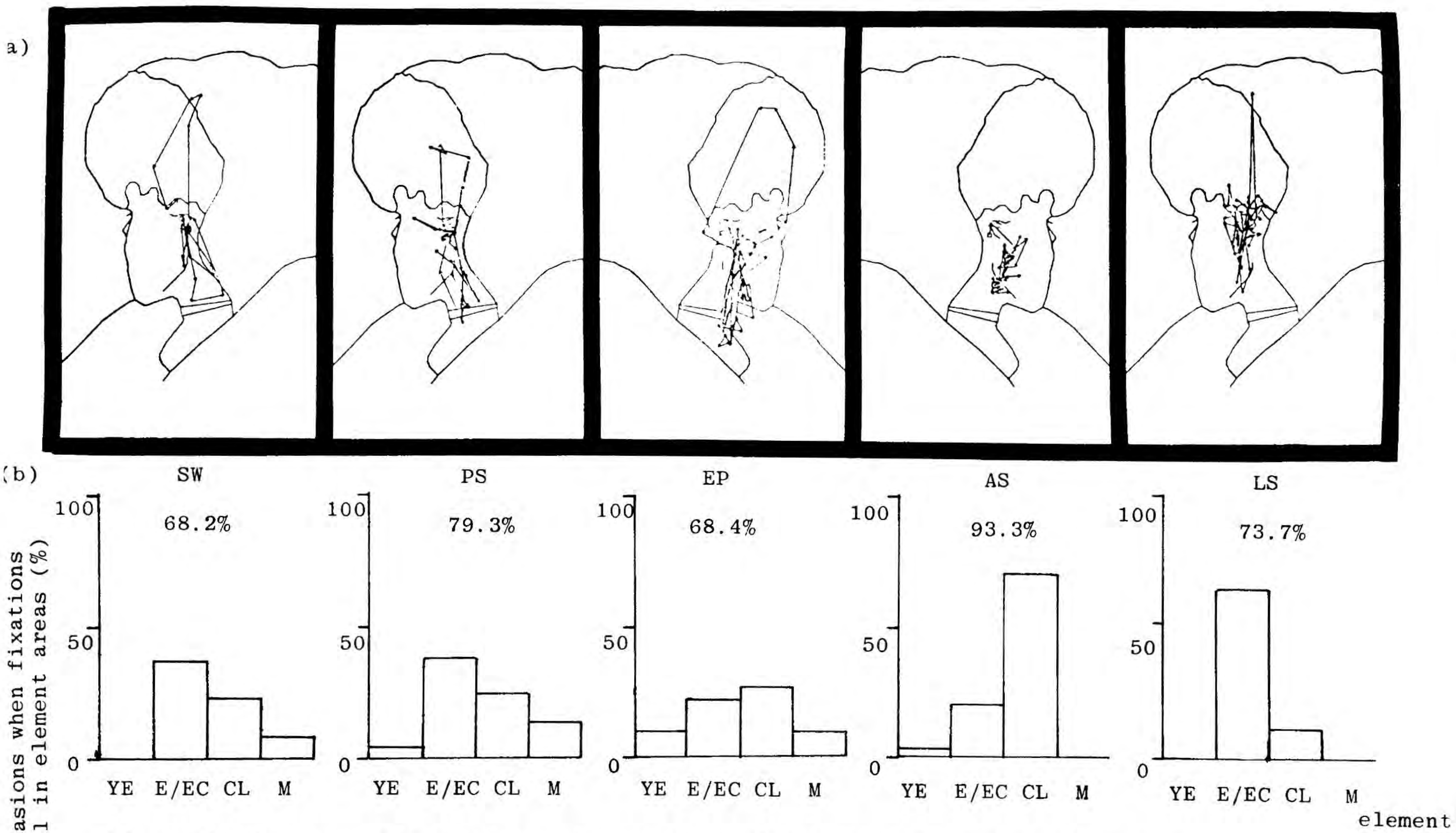


Figure 6.5 Patterns of scanning and percentage of fixations in each element area when instructed to concentrate on the YW aspect.



<u>Figure 6.6</u> Patterns of scanning and percentage of fixations in each element area when instructed to concentrate on the OW aspect.

of fixation upon the YE element. EP concentrated on the YE element but also scanned once around the general facial area of the stimulus.

The concentration of fixations upon the YE or E/EC elements is shown in the graphs in Figure6.5(b). Three Ss fixated most in the YE area with the E/EC area being the next most often fixated. Two Ss (AS and LS) made more fixations in the E/EC area. All 4 Ss showed complete absence of fixating the M area and for 2 Ss (EP and LS) the CL area was also not scanned.

Old woman aspect. In response to the instruction to concentrate on the OW aspect for 10s the resulting eye movements are shown in Figure 6.6. The scanning patterns do not encompass the YE element instead they cluster around the M, E/EC and CL elements. Subject AS only encompassing the E/EC and the CL elements. The majority of fixations for each S fell in either the E/EC or CL area (Figure 6.6(b)). The YE area was rarely fixated and also the M area was fixated by 3 Ss on about 10% of the time. Both of these results are in contrast to those for the previous condition.

Alternation conditions. In the remaining 6 conditions Ss alternated between the two aspects. These are initially considered with reference to Figures 6.7-6.12. These Figures show the fixation locations of the 5 Ss plotted according to their response state for each stimulus condition. A key to the interpretation of the symbols used in these plots is given with Figure 6.7 . The initial NO response is the S's fixation position when the central fixation cross was present. The ST state represents the fixation location when the stimulus was initially presented. YW and OW represent young woman and old woman and NR is when neither response button representing these 2 alternate aspects was pressed during the experimental trial.

When the Ss alternated between each aspect of the full line drawing fixations clustered around the four elements (Figure 6.7(a)). As in the previous two conditions the YW aspect was generally reported in the area of the YE-E/EC elements, whereas the OW aspect was reported between the E/EC and the M element. Subject LS reported OW near the E/EC element and YW near the YE element.

The percentage of fixations made in each 'element area' is shown in Figure 6.7(b). Two Ss (AS and LS) made most fixations near the E/EC element whereas the other Ss made more fixations near the YE element.

In the absence of the YE element (Figure 6.8 (a)) YW was still reported and S's still fixated in this part of the stimulus. Four Ss first reported the YW aspect. Each S reported YW or OW aspects in similar regions of the stimulus as for the previous condition. For all Ss the majority of fixations fell in an area encompassing the E/EC element with the YE element area being next most favoured (Figure 6.8(b)).

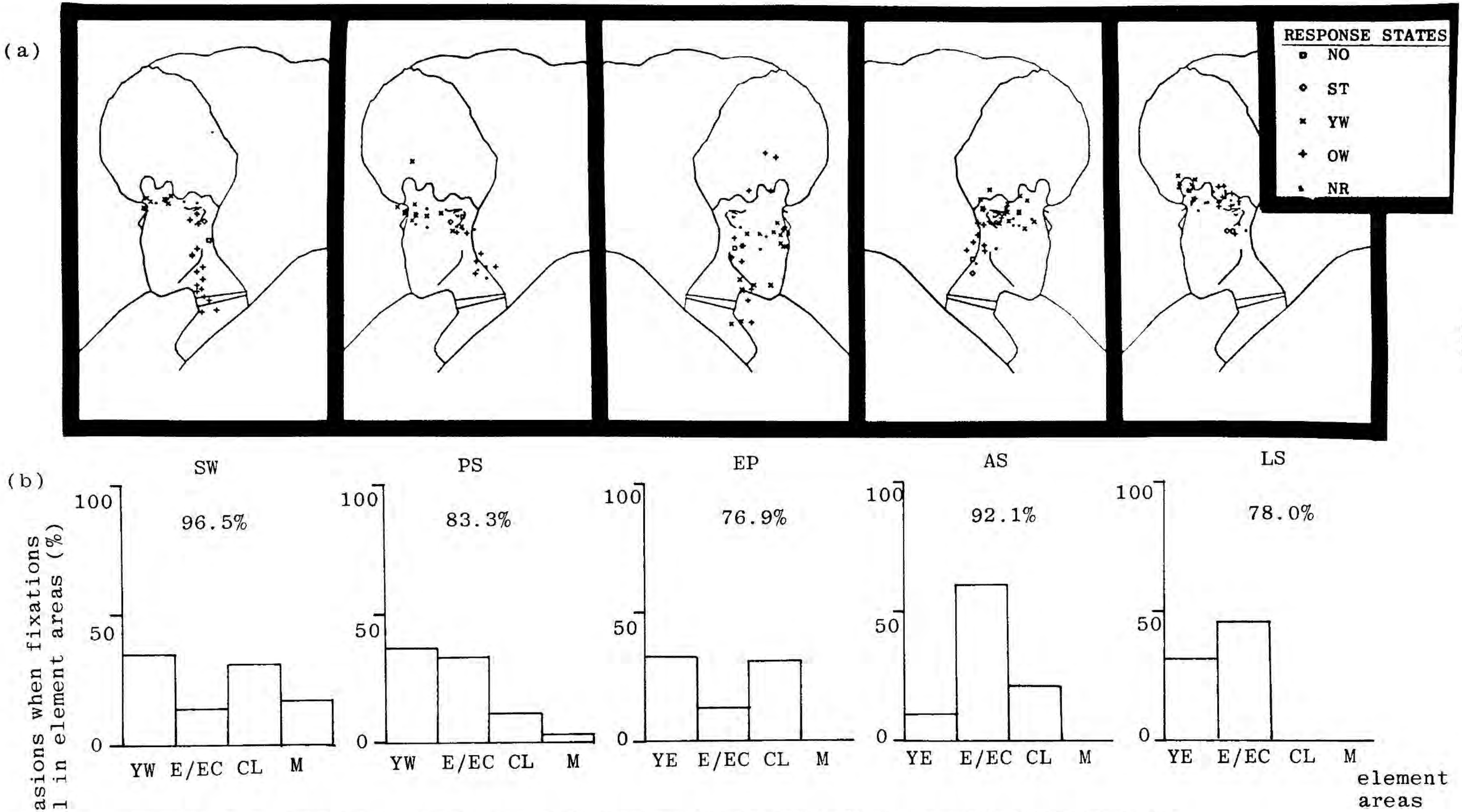
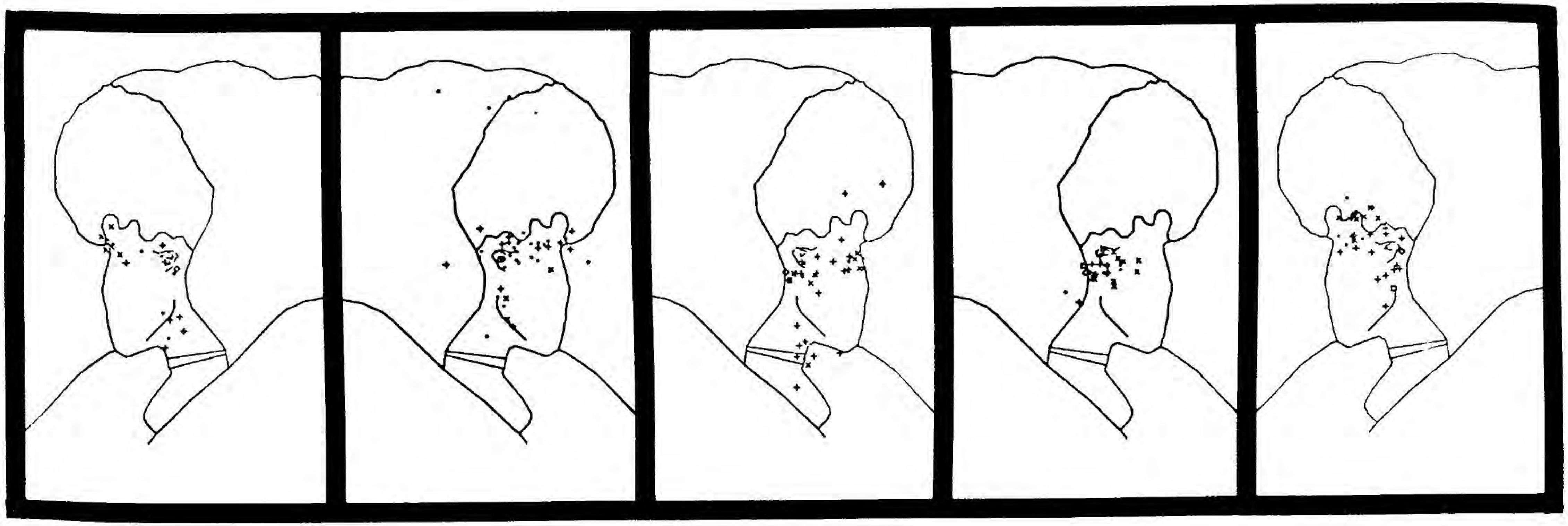


Figure 6.7 Fixation locations and percentage of fixations in each element area when alternating on the full ambiguous figure.

(a)



(b)

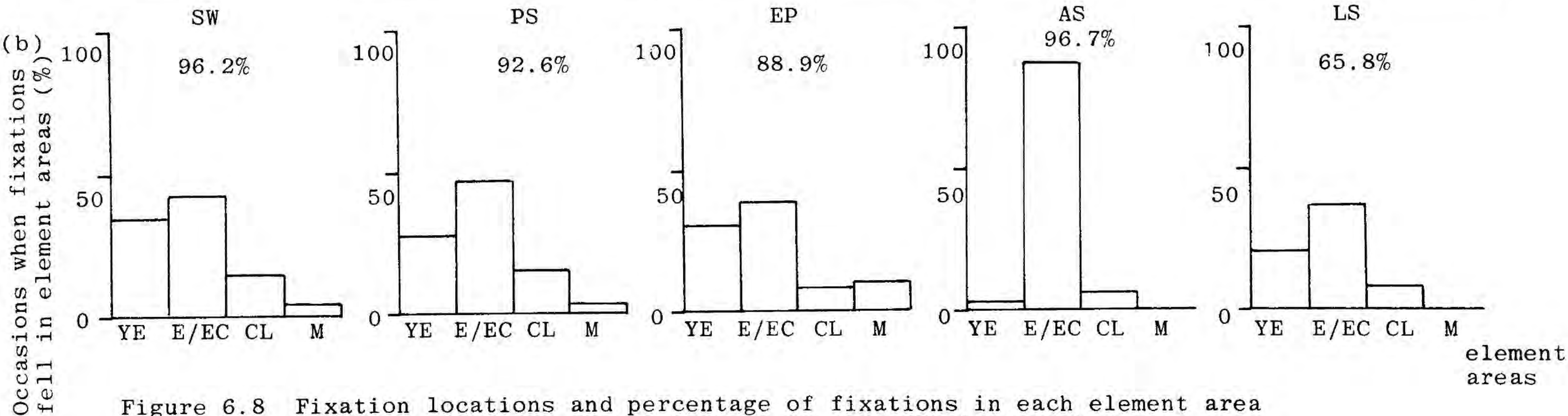


Figure 6.8 Fixation locations and percentage of fixations in each element area when alternating on the stimulus with the YE element absent.

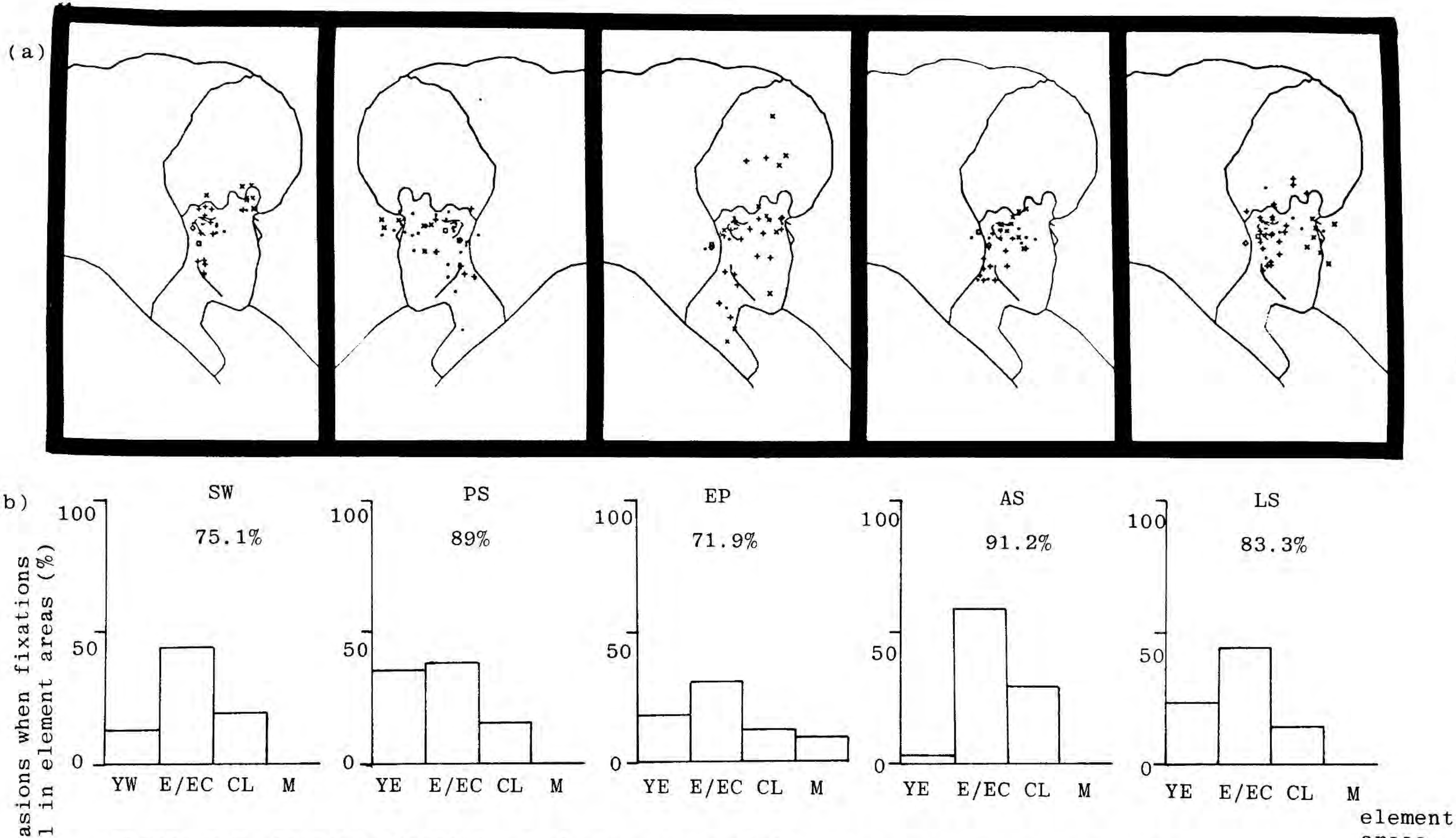


Figure 6.9 Fixation locations and percentage of fixations in each element area when alternating on the stimulus with the M element absent.

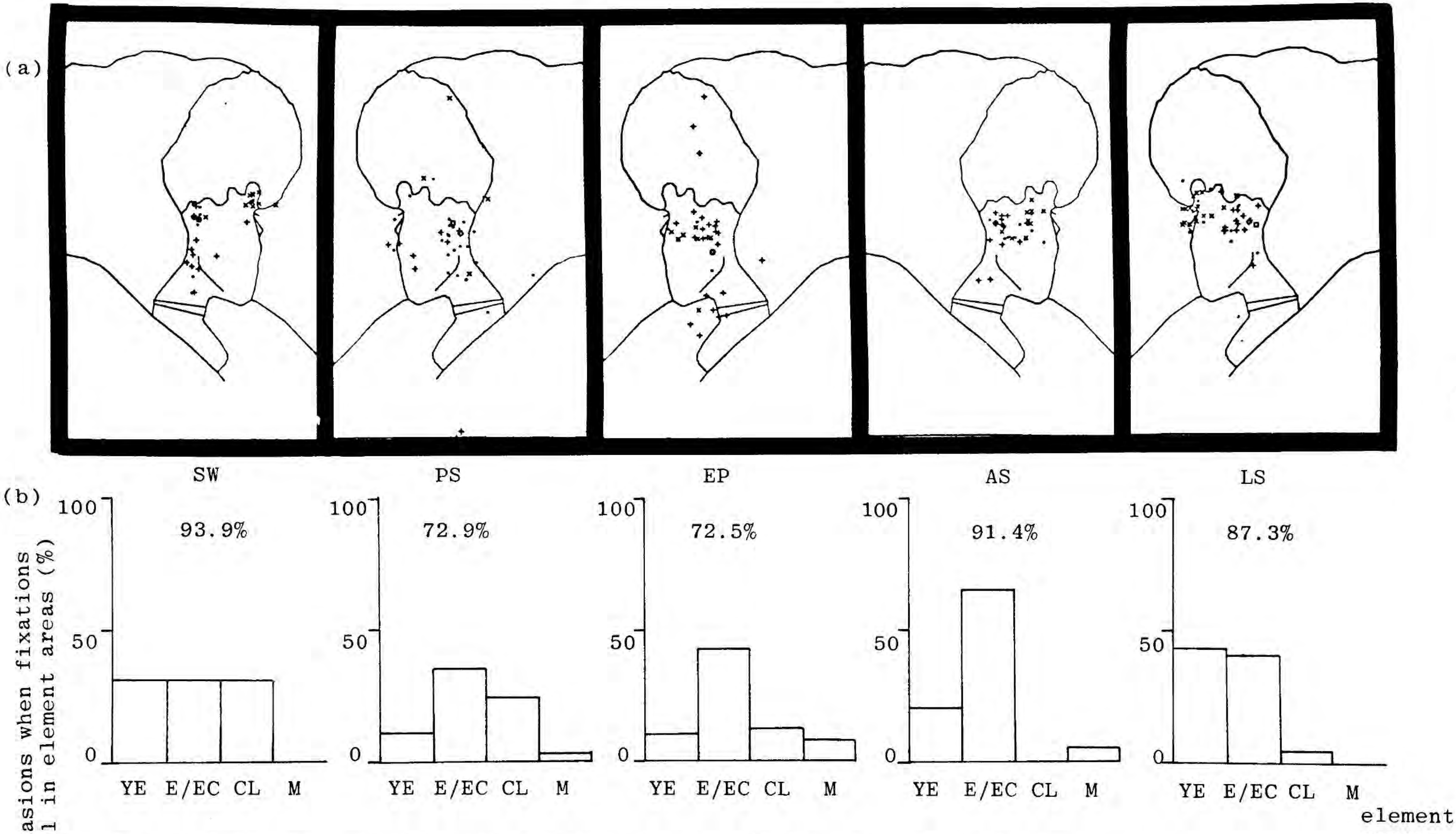
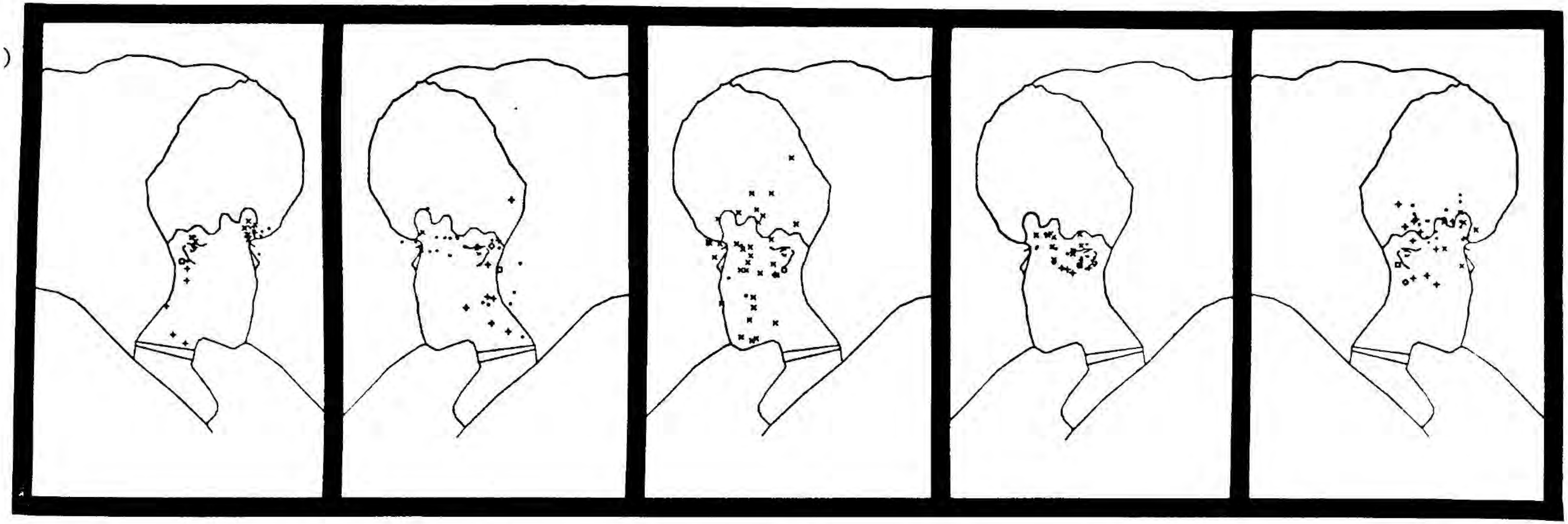


Figure 6.10 Fixation locations and percentage of fixations in each element area when alternating on the stimulus with the E/EC element absent.

(a)



(b)

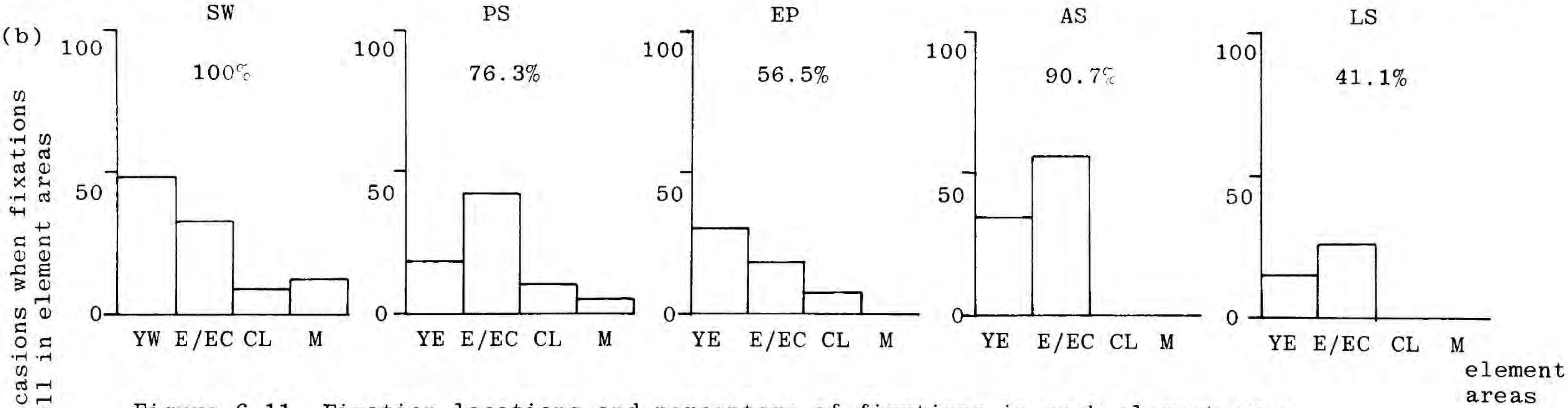
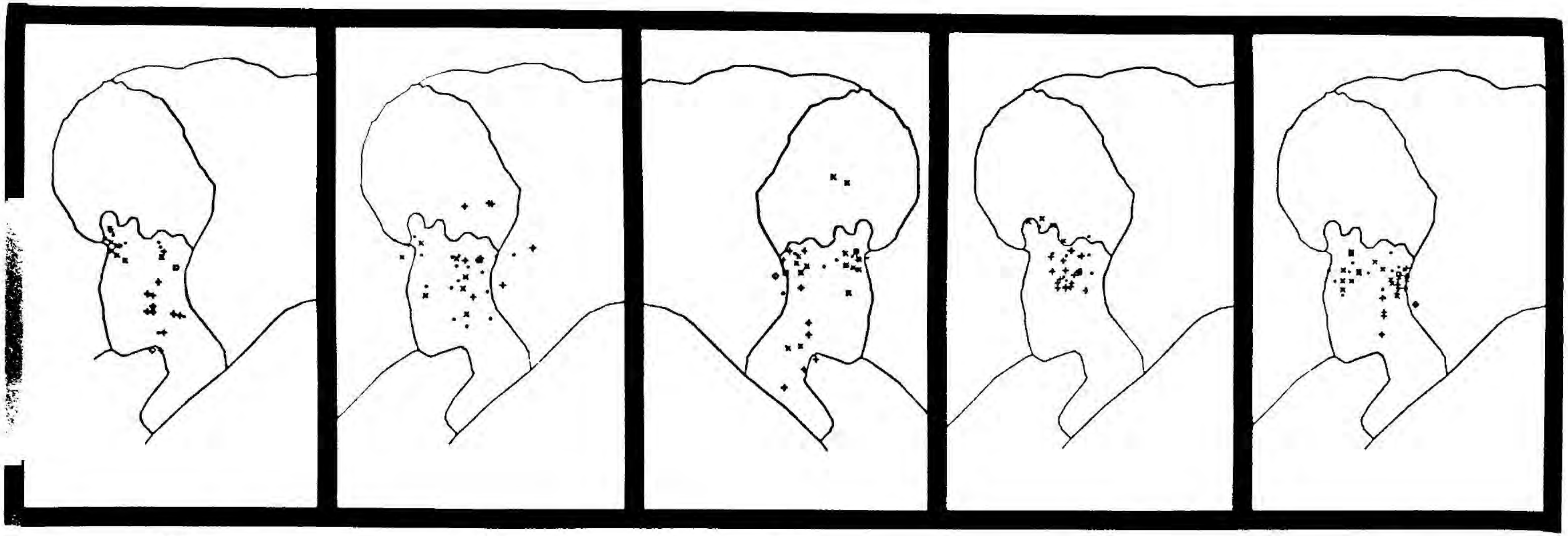


Figure 6.11 Fixation locations and percentage of fixations in each element area when alternating on the stimulus with the CL element absent.

(a)



(b)

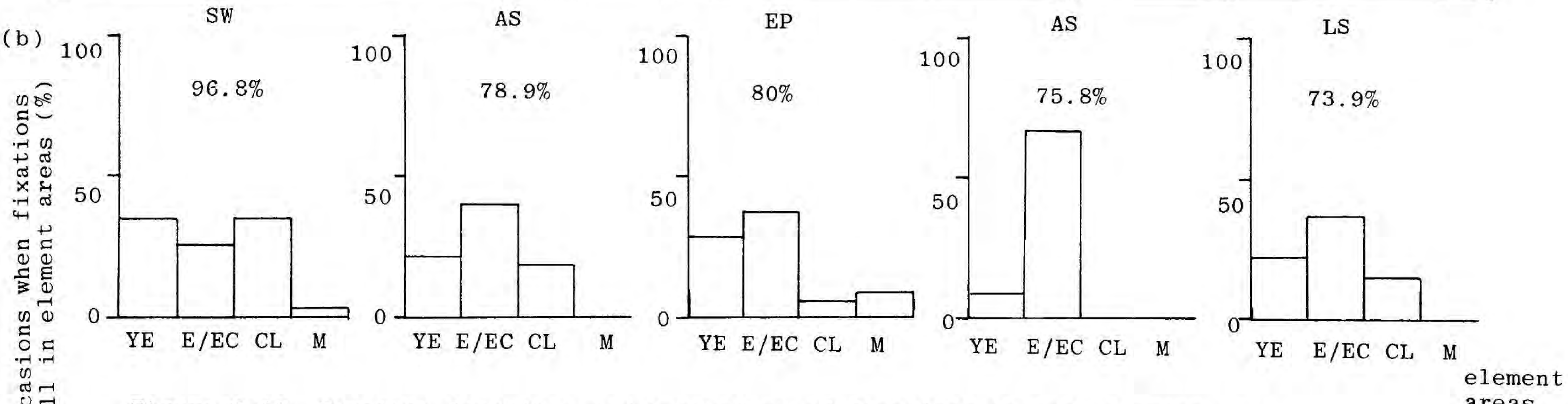


Figure 6.12 Fixation locations and percentage of fixations in each element area when alternating on the stimulus with no elements present.

In the absence of the M element (Figure 6.9(a)) 3 Ss first reported the OW and 1 S the YW aspect. Only 1 subject (EP) fixated where the M element would have been, the other 4 Ss fixated in the upper part of the face and near the CL element. This is made clear in Figure 6.9(b) where the highest percentage of fixations made by each S was in the E/EC area. Young or old woman was generally reported by each S in similar parts of the stimulus as when they alternated on the full line drawing.

When the E/EC was absent (Figure 6.10(a)) all Ss still fixated in this area of the stimulus. For 3 Ss this stimulus area (Figure 6.10(b)) was the most often fixated although for 2 Ss (LS and SW) the YE area was as equally often favoured. Again the M area was generally fixated least. Each S again tended to fixate broadly similar stimulus regions as for the first alternation condition.

When the CL element was missing (Figure 6.11(a)) only 3 Ss (PS, SW and EP) fixated in this region. Three Ss reported YW or OW in similar regions of the stimulus as in the first alternation condition. EP only reported the YW aspect even when fixating towards the 'nose' of the old woman whereas AS only fixated near the YE and E/EC elements. From Figure 6.11(b) for 3Ss the E/EC area was fixated most and for 2 Ss (SW and EP) the YE area was most often fixated.

When none of the elements were present in the stimulus Ss fixated in similar regions as had previously been occupied by elements(Figure 6.12(a)). An area encompassing the E/EC element (Figure 6.12(b)) received the greatest number of fixations with the YE area being the next most favoured by all Ss.

In the graphs of Figures 6.4-6.12 the overall number of fixations made in the defined 'element areas' is shown as a percentage of the total number of fixations made on the stimulus in the 10s period. The percentage of fixations falling in these regions ranges from 41.1 - 100% with an overall mean of 79.4%. For each S across all the 9 ambiguous figure conditions the majority of fixations fell in these areas. This can be expressed as an overall percentage for each S as follows; for SW-84.4%, PS-77.5%, AS-89.2%, EP-73.2%, LS-72.6%.

Alternation eye movements. The same conditions are plotted in a different format in Appendix F . Again the S's response state is given by similar symbols. Each time there is a change in the response an arrow is used to join the two fixation locations. Blinks during the change of response are shown by a dotted line. The fixation location immediately before the S's first response (this being YW or OW) is shown circled. The response state of YW, OW or NR (no response) is also shown for each S in an accompanying graph to the actual plots of fixation positions. Each graph represents these 3 response states over the 10s period of the experiment and shows the fixation times, saccade lengths and blink occurrence for each S. An explanation of these graphs is given at the beginning of Appendix F .

From these plots showing the eye movement during a change of response it is evident that no S fixates exactly the same part of the stimulus during alternation on a single stimulus. Although for some Ss over all the conditions there is some general consistency in these alternation movements.

For instance, EP makes a large vertical movement approximately between the E/EC and M elements on 4 stimuli. Also for each condition all 5 Ss alternate across different areas of the stimulus although there is evidence in many cases of alternation that the E/EC element is fixated.

All Ss exhibited saccades in the NR state between responding young or old woman. One S (PS) particularly made several eye movements whilst not responding as either aspect.

The eye movement between the change of the S's response can be considered with reference to the 'element areas' as defined in Figure 6.2. In this way these movements can be categorised as occurring within or between certain areas. Table 6.1 shows the number of times such movements were made in each 'element area' for each S on the 6 alternation conditions. The initial changes from NO and ST to NR states are not included in this data.

		WITHIN ONE AREA				BETWEEN ELEMENT AREAS						
Subject	Condition	YE	E/EC	CL	M	M-E/EC	E/EC-CL	E/EC-YE	CL-M	M-YE	CL-YE	Other
SW	ALL p	2					1	2		1		
	YE a	2	3				1	1				
	M a	2	3									
	CL a	2	2		1		1	1				
	E/EC a	1	2				1		1			
	ALL a	2	2	2			1				1	
AS	All p		3	1			1					
	YE a		4									1
	M a		5									
	CL a		5									
	E/EC a	1	3					1				
	ALL a		2									1
EP	ALL p	3						2				
	YE a	1	1						1			
	M a	2				1						
	CL a										1	
	E/EC a					1		2				
	ALL a	1	1				1	1				1
PS	ALL p	3	4	1			1					
	YE a	1	3	1					1			
	M a	3	5									
	CL a	3	3	2					1			
	E/EC a	4							1			
	ALL a						2	1				
LS	All p	4	2					2				
	YE a	3	2				2	2				
	M a	3	1					1				
	CL a	1	3									3
	E/EC a	3	1					6				
	ALL a		2				2	3				

Stimulus conditions are denoted by whether the elements were all present (ALL p), all absent (ALL a), or only 1 element absent. Element areas are represented by the appropriate letter. 'Other' is when the eye movement occurred outside these areas.

Table 6.1 The number of occasions when an eye movement between a change of response occurred within one element area or between 2 element areas for each subject.

Most of these alternation eye movements occurred within either the E/EC or YE element areas for all Ss. Individual differences are apparent such that each S tended to use similar alternation eye movements between or within such 'element areas' on all the stimulus conditions. For example, for 5 of the stimuli LS made movements between the YE and E/EC areas whereas SW made movements between the E/EC and CL areas on 4 of the stimuli.

These alternation eye movements are further enlarged upon in the following discussion.

General results. The response sequence together with the occurrence of blinking is shown in Table 6.2 . Most Ss reported some 3 alternations in the 10s period for each stimulus. One S (EP) showed a low alternation rate. For one condition only reporting the YW aspect and on 4 conditions only changing once between aspects. In contrast LS reported each aspect twice on four occasions. Blinking was evident for 4 of the Ss both during the response of young or old woman as well as in the intervening changeover between these two response states. As shown in the graphs in Appendix F blinking sometimes effectively produced a large change in fixation location as shown by long 'saccade lengths'.

	STIMULUS CONDITIONS					
		MISSING ELEMENTS				
SUBJECT	All Elements Present	M Absent	CL Absent	E/EC Absent	YE Absent	All Absent
SW	-Y-O-YO + +	-O-Y-O * *	-Y-O-Y- +	-Y-O-Y +	-Y-O-Y-O	-Y-O-Y-O-
PS	-Y-O-Y-O-Y	-O-Y-O-Y-	-O-Y-O-Y-O	-O-Y-O *	-O-Y-O-	-Y-O + *
EP	-Y-O-Y *	-O-Y * *	-Y	-Y-O +	-Y-O +*	-Y-O
AS	-Y-O-Y +	-Y-O-Y * **	-Y-O-Y *	-Y-O-Y *	-Y-O-Y	-O-Y
LS	-O-Y-O-Y-	-O-Y-O	-O-Y-O-Y	-Y-O-Y-O-Y	-O-Y-O-Y-O	-Y-O-Y-O

KEY:-

Y = Young Woman
O = Old Woman
- = No Response
* = Blink in this response
+ = Blink during change to next response from the present one

Table 6.2 The response sequence for each subject in the alternation conditions.

		STIMULUS CONDITIONS																	
		All Elements Present			MISSING ELEMENTS														
					M Absent			CL Absent			E/EC Absent			YE Absent			All Absent		
SUBJECT	RESP.	N	FT	SL	N	FT	SL	N	FT	SL	N	FT	SL	N	FT	SL	N	FT	SL
SW	NR	6	1.6	10.1	9	2.94	10.7	9	3.46	16.8	7	2.0	12.5	11	3.0	24.4	10	3.0	22.8
	YW	6	3.42	34.0	9	2.24	6.9	9	4.14	9.3	11	4.04	12.8	6	2.8	2.9	10	3.6	10.7
	OW	16	4.98	34.0	13	4.82	24.2	6	2.4	10.7	13	3.96	23.5	8	4.2	12.1	11	3.4	16.9
PS	NR	16	4.3	21.3	31	7.34	48.1	25	5.56	40.5	23	6.56	40.5	27	6.78	58.1	21	5.72	33.4
	YW	13	3.1	14.0	7	1.48	12.7	2	4.7	2.0	4	0.8	17.9	3	0.52	5.6	7	1.38	12.6
	OW	6	2.6	4.5	6	1.18	8.5	10	3.49	18.3	9	2.64	32.0	12	2.7	20.0	9	2.9	16.0
EP	NR	8	1.72	8.7	8	2.0	17.7	6	1.4	12.1	6	1.8	13.1	7	1.9	11.3	8	2.76	13.1
	YW	17	4.46	27.2	10	2.96	27.0	32	8.6	85.5	7	1.7	16.0	9	3.1	17.1	16	4.96	28.6
	OW	13	3.82	29.9	20	5.04	50.1	0	0.0	0.0	24	6.5	67.0	19	5.0	48.5	10	2.28	25.2
AS	NR	8	2.16	11.8	11	2.72	14.5	13	3.2	16.3	11	2.6	11.0	8	2.36	9.4	12	2.6	11.5
	YW	18	5.08	22.4	7	2.28	5.3	10	3.84	10.0	8	2.8	6.4	10	3.64	11.3	3	1.42	3.8
	OW	11	2.76	13.6	15	5.0	18.3	8	2.96	7.1	15	4.6	18.6	12	4.0	9.2	17	5.98	14.1
LS	NR	21	5.32	21.8	12	2.96	21.2	20	4.6	23.3	17	3.8	31.2	11	2.8	13.3	19	3.96	25.5
	YW	8	2.2	7.4	7	1.56	9.9	6	2.8	8.8	15	3.3	19.7	7	2.0	7.0	14	2.92	17.4
	OW	11	2.48	14.1	22	5.48	34.0	12	2.6	16.8	14	2.9	20.8	19	5.2	29.6	12	3.12	13.5

Table 6.3 The total number of fixations (N), total fixation time (FT), and total saccade length (SL) found for each of the subjects' response states in the 6 alternation conditions.

Table 6.3 shows the total number of fixations, the total fixation times and total saccade lengths made in each of the three response states by the Ss in every alternation condition. Here the NR response state is taken from the moment the stimulus was presented (i.e. it includes the ST state).

After the experiment no S reported any awareness that his eye movements had been recorded and all expressed surprise that this had been the case. The Ss regarded the experimenter as simply recording the duration during which either the young or the old woman aspects were reported. When questioned as to their response procedure all affirmed that they had kept the appropriate response button depressed during the time that each aspect was perceived.

6.2.6. Discussion

The Noton and Stark 'face' stimulus was presented first to see if Ss fixated similar regions on this line drawing of a face as on the ambiguous line drawing. Patterns of eye movements on this stimulus demonstrated that Ss fixated informative facial regions such as the eye. On initial presentation of the line drawing of the ambiguous figure each S exhibited a different pattern of scanning with fixations concentrating on the E/EC and YE elements (i.e. the eyes). Individual differences in eye movement patterns have been reported elsewhere (Buchsbaum, Pfefferbaum and Stillman, 1972) and there are many reports of Ss fixating informative stimulus regions (e.g. Baker and Loeb, 1973; Zusne and Michels, 1964; Yarbus,1967 ; Buswell,1935). Such informative regions in the present experiment are considered to be the pictorial elements of the stimulus.

When asked to concentrate on the young or old woman aspects then fixations were limited to distinctly different areas of the stimulus. For the YW aspect fixations occurred between the YE and E/EC elements, whereas for the OW fixations were between the E/EC and M elements. This is as was hypothesised and confirms the results of Experiment 1 which demonstrated that as a controlled fixation position moved towards the YE element then more YW responses were obtained. In contrast more OW responses were found for fixation locations lower in the picture particularly towards the rear of the M element.

These results confirm those of Sakano (1963) who asked Ss to similarly concentrate on the YW or the OW aspect of Boring's ambiguous figure and obtained the patterns of eye movements shown in Figure 2. 2 . When asked to concentrate on the YW aspect, eye movements were limited to the upper part of the face and on what here have been termed the YE and E/EC elements. When asked to 'watch' the figure as an old woman eye movements occurred over the whole of the face region and not just on one part of it. The patterns obtained in the present experiment were much more restricted than were obtained by Sakano, possibly due to the use here of an outline drawing of the stimulus.

When the S subsequently alternated between the two aspects on the full line drawing then again the OW aspect was reported between the M and E/EC elements and YW in the YE-E/EC area. One S (LS) did not fixate low in the picture at all, but still reported YW near the YE aspect and OW near the E/EC. Again this further confirmed the distribution of responses for different fixation positions across the stimulus.

When viewing the stimulus without the YE element then it was hypothesised that the first response would be to the OW aspect. Instead 4 Ss first responded YW aspect. The OW response had been predicted on the basis of the previous demonstration (Experiment 4 and 5) that stimuli without this element present were responded to as the OW. Here the initial fixation position was central on the stimulus and it was thought that the first eye movement would be towards the M element thus eliciting an OW response. Instead, all Ss first made movements in the upper part of the facial area(Figure F.2, Appendix F). 3 Ss executed movements towards the missing YE element and all of these reported YW. Two Ss reported YW first while fixating near the E/EC. This finding of YW response is then in agreement with the afterimage experiments which showed that fixating in the upper part of the facial area produced a greater likelihood of a YW response whether or not the YE element was present. When the M element was omitted a first response of YW was hypothesised to occur, again on the basis of the previous results of Experiments 4 and 5. Instead, in 4 cases an OW response was first given (Table 6.2). From Figure F.3 (Appendix F) two Ss (LS and EP) first executed an eye movement towards the lower part of the facial region before responding as OW, 2 other Ss (AS and PS) whilst fixating near the E/EC reported OW and YW first. The remaining S reported OW first whilst fixating near the E/EC element.

Subsequent fixations on this stimulus did not generally encompass the area of the M element. When the CL or E/EC were omitted no consistent effect of first response or an initial eye movement direction before a first response was given was found (Figures F.4 and F.5, Appendix F). In the absence of the E/EC element fixations in this stimulus region still occurred, PS was the only S who fixated on the region of the CL when this latter element was absent. Complete absence of all elements (Figure 6.12 and Figure F.6) elicited fixations in the regions of the missing elements.

In these conditions of one or all missing elements the finding that Ss still fixated in such 'missing-element' regions can be interpreted in two ways. Firstly, this line drawing stimulus is very simple (it was constructed in this way for reasons described in Chapter 3) and so a missing element in a free viewing situation is very obvious. The S may then fixate this region simply as part of a search strategy for this element. Secondly, the S may need to fixate this area in order to respond as one particular aspect.

Both interpretations are consistent with a schematic map proposal where the S's map effectively 'tells' him where to fixate so as to maximise the likelihood of one aspect's response. This is certainly the case from the distribution of the S's responses of young or old woman. Individual differences in such schematic maps would also have to be predicted to explain the different fixation locations exhibited by the different Ss (e.g. AS shows fixation distributions concentrating for all the stimuli around the E/EC element).

One of the characteristics of a schematic map as proposed by Hochberg (1970a)is to tell the S what to expect at some location and if this information is not subsequently found then the map has to be capable of alteration to accommodate this. The present results suggest that in the case of the different versions of the ambiguous figure the map did not change but rather it acted to 'drive' the S to fixate a particular stimulus area whether or not the expected element was present there. This agrees with other work which has demonstrated a failure of a S to report missing parts of a stimulus display even when such parts are grossly obvious, e.g. Tuddenham (1962) found failures to notice an amputated female breast on a chest x-ray and Gale, Johnson and Worthington (1979) report a similar example with a leg amputee.

When fluctuations occurred fixations were subsequently made to an area, as determined in the afterimage experiments, favouring either the YW or OW aspect. As discussed in Chapter 2 previous research has attempted to determine whether a saccade precedes or follows a change in the S's response of perceived aspect. As also pointed out in that chapter the 'high probability areas' or elements of the stimulus are typically not previously determined so that the occurrence of an eye movement to such an area can be ascertained. Here such elements were previously determined.

The instructions to Ss were to report any fluctuations, they were not instructed to drive such fluctuations as fast as possible or to attempt to inhibit them (essentially the instructions to concentrate on either aspect are such 'hold one aspect' instructions). The dual button response was first practised by Ss and was used to permit a 'neither aspect' response. What is apparent from the Figures presented in Appendix F showing the time course of these fluctuations is that such a no response state was found for every S. This was not simply due to the response procedure as several saccades were made during this time and individual differences were found in the duration of such no response times (e.g. PS exhibited long no response times with many saccades for these stimulus conditions). In this experiment the fluctuation from one aspect to the other involved several intervening eye movements with neither aspect being reported by the S. This no response period may then reflect 'perceptual idling' with fixations being made with no definite expectation of a particular aspect. However, in no case did the S revert to the previous response and so this period really is where neither aspect was clearly perceived.

Of particular interest are those changes representing alternation from YW or OW to the NR state or vice versa. These occur at various points in the stimulus and each individual exhibits some consistency in these locations over the different stimulus conditions (Table 6.1). On some occasions the eye movement made before a change of response was indicated occurred from one 'element area' to another favouring the alternate aspect but in the majority of cases a change of response was not immediately preceded by an eye movement from one 'element area' to another. Most of these movements occurred within either the YE or E/EC 'element areas'. This confirmed the hypothesis that alternation can occur without a major change in fixation location although the findings of the intervening 'no response' state between young and old woman responses complicates this.

Ellis and Stark(1978) found that the fixation time before a change of response on the Necker cube was longer than usual interpreting this extra time as necessary for the're-organisation' of the response. In the present experiment the NR state complicates exactly which fixation ought to be regarded as the 'organisational' one - the last one of a response or the last one of the NR state - and also the technique of reducing the data by combining adjacent fixations except when a change of response occurs results in the majority of these fixation times being 0.2s. For these reasons such analysis of these times was not pursued.

One technique of changing fixation location was blinking which was found for 4 Ss (Table 6.2). This occurred both during a response of YW or OW and during the change from one response to the other. Blinking has previously been reported to be a technique used by some Ss to alter perception of such stimuli - as discussed in section 2.3.9.

The fixation position of a S did not always coincide with a point on the stimulus display. This in some instances represents the error of measurement of the recording technique but in many cases it demonstrates an actual fixation not on part of the stimulus. This also occurred for the first fixation of a new response after alternation. The tendency for Ss not to fixate the M element a great deal may possibly be related to the ability to usefully perceive this element peripherally. This was demonstrated in Experiments 2 and 3 where altering this element affected Ss responses even when they were fixating higher up in the stimulus.

For each S fixations tended to recur in approximately the same locations. This is shown by the superimposition of fixations and by the percentage of fixations occurring in each element area. Such repetitive eye movements have earlier been reported by Yarbus (1967) and also Zusne and Michels (1964). Noton and Stark (1971a, b, c) argued that such movements were related to the recognition of the stimulus. They proposed that the actual sequence of eye movements and fixation locations were involved in the representation of that stimulus in memory. This is rather like the schematic map proposal except that Noton and Stark argued that for the later recognition of the stimulus essentially the same sequence of eye movements and fixations (termed a scanpath), as performed by the S when learning the stimulus, is then executed. To allow for internalised attention shifts the internal representation of the stimulus, a feature ring, was elaborated into a feature network with the scanpath being a preferred sequence in this network.

The scanpath proposal has not been without its critics (e.g. Spitz, 1971; Didday and Arbid, 1975). Locher and Nodine (1972), using simple random shapes, found such scanpaths in about half of their Ss' eye movement patterns but without any indication that they helped aid recognition. Gould (1967) has also reported regular scanning sequences although other work has not found them (e.g. Mackworth and Bruner, 1970). Mackworth (1967) has argued that eye movements essentially assemble a pattern image in memory in any order, not in a particular sequence as in a scanpath.

Eye movements and fixations may be involved in the representation of an object in memory (e.g.Loftus,1972) but such movements are not solely determined by an internal plan as in Noton and Stark's theory. Walker-Smith, Gale and Findlay (1977), in a face recognition task, have reported regular scanning sequences which differed between Ss. It was proposed that these sequences did represent some structuring of the eye movements and fixations but that this was not solely a result of the internal strategy determining the next fixation. Rather, it was argued that peripheral information executed some control over the next fixation location in interaction with the internal schema, a proposal similar to that for the present stimuli. This work was carried out with the same equipment as used in the present experiment and the published paper is included as AppendixG .

It is proposed then that the S, through first familiarising himself with the ambiguous figure, has acquired two schematic maps. The different elements of the ambiguous figure are essentially weighted in their representation of each aspect in these maps. As the S views the stimulus his eye movements are determined both by peripheral visual information and by the ongoing testing process of the current map. Fluctuations occur when this testing of the schematic map expectations falters and fixations are subsequently made with little or no definite expectation which then leads to the instigation of the alternate map being tested. The model of this process is developed in the next chapter.

6.3. SUMMARY

This experiment in which Ss' eye movements were recorded as they viewed the ambiguous figure further confirmed the earlier results that each aspect of the ambiguous figure was favoured by fixation in different areas of the stimulus. It is argued that this represents the S attending to different stimulus elements.

The afterimage experiments demonstrated that if fixation position was not changed but the presence of elements were altered then this affected the response of figure. In the present experiment when Ss could freely view the stimulus then altering elements did not affect their fixation location on the stimulus. Ss often fixated where the missing elements should have been. This was interpreted as demonstrating that in this case the schematic map acts to 'over-ride' the stimulus information.

Previous experiments (Experiments 4 and 5) showed that a S's immediate response to altered versions of the stimulus was affected by which elements were present in the display. In the present experiment Ss alternated on the stimulus and in so doing fixated stimulus areas which had a high probability of representing one aspect. The act of alternation was accompanied by a period in which no response was made. This may represent perceptual idling as suggested by Hochberg (1970a).

C H A P T E R 7

CONCLUSIONS

7.1. OVERVIEW

The work presented in this thesis has investigated the role of eye movements in figure perception by first elucidating the distinction between figure and ground and then considering the different types of stimuli which can give rise to more than the one interpretation of figure. These were classified as ambiguous or reversible perspective figures. The importance of such stimuli is that they enable examination of how the response of figure has occurred.

Much previous research has either directly or indirectly examined whether eye movements are involved in this perception of figure. The main interest has been whether eye movements are causally related to figure perception such that a movement has to be made before the stimulus is perceived to change from representing the one figural aspect to another.

Indirect studies using approaches such as maintained fixation or small stabilised images have found that alternation can still occur. This has been taken by some workers to demonstrate that eye movements are not necessary to figure perception. However eye movements may still occur in these situations even though, as in the stabilised conditions, they may not cause a change in fixation position upon the stimulus. A more difficult problem for an explanation stressing eye movements is where the stimulus is created post-retinally such as with stereograms.

Direct studies where eye movements have been recorded when Ss viewed ambiguous or reversible perspective figure have generally produced inconclusive results and have been criticised here for possibly contaminating the very variable of interest.

It was proposed here that what was of importance in the perception of figure was visual selective attention and that the relevance of eye movements was as the main instrument of this process. Thus in stereograms, or small stabilised images, alternation between figural aspects occurred because the observer was able to shift attention and so alter the perception of figure. Hochberg's (1968) schematic map concept was proposed to offer a plausible account of the operation of such selective attention in which stimulus parts 'glimpsed' in each fixation are sequentially tested against the expectation of the ongoing map.

From the consideration of the manner in which ambiguous figures have been manipulated to produce stimuli representing only a single aspect it was proposed that both ambiguous and reversible perspective figures could essentially be considered as containing parts or elements. These were considered to be differentially biased or weighted towards one or other figural interpretation and that the response of figure was largely as a result of selective attention to such elements.

To investigate this proposal Boring's ambiguous figure was selected as a suitable stimulus and Ss first made aware of both of its figural interpretations. This was to overcome any tendency by the S to only perceive the one aspect. It was then presented as a large stimulus in a stabilised condition where the S could only attend to certain stimulus parts. Boring's figure was first simplified to a line drawing to facilitate good afterimage appearance and it was proposed that this line drawing could be considered as containing 4 main elements. Two of these elements were proposed to be strongly weighted in favour of one or other aspect with the remaining 2 elements being not so extremely biased. The response of figure was proposed to depend upon the relative weightings of the elements to which the observer could attend. That is, these weighted elements instigated one particular schematic map as opposed to the alternative. The likelihood of one map being undertaken increased as the weightings of the elements in favour of this map also increased.

The first afterimage experiment demonstrated that as the fixation position was altered on the stimulus prior to painting the afterimage then the response of figure was affected in a predictable manner. More young woman responses were obtained for a fixation position near the YE element which was considered to be strongly weighted in favour of this aspect. In contrast more old woman responses were found for fixations near the M element which was proposed to be strongly weighted towards this alternate aspect. These results were interpreted as confirming the importance of being able to attend to particular stimulus elements.

When the 4 elements were then altered in 2 further afterimage experiments then the response of figure was changed in that the figural interpretation for which the elements omitted from the stimulus were least weighted was enhanced. This occurred even when the altered element was rather peripherally viewed demonstrating that both foveal and peripheral vision were important factors. Interaction effects between fixation positions and elements present in the display were interpreted as further supporting the role of both types of vision.

The afterimage experiments used a controlled fixation position upon the stimulus to determine the S's focal attention. However similar results were obtained in 2 free viewing experiments when these elements were either present or absent and when Ss, either students or children, were asked to immediately respond as one or other aspect. These findings extended the generality of the afterimage results by again demonstrating that the response of figure was dependent on the elements present in the display. These studies also showed how important the YE element was in instigating the young woman schematic map in such free viewing situations. No age differences in response to these stimuli were found which demonstrated the utility of such elements was not age-related although it was suggested that the precise way in which they were integrated into a schematic map may possibly be.

To further elaborate the role of eye movements in the perception of this ambiguous figure a technique of recording eye movements inconspicuously was then designed and constructed. In an experiment were Ss were instructed to concentrate on one or other aspect and their eye movements recorded, it was found that these movements were limited to parts of the stimulus which had been determined to be strongly weighted towards that aspect in the afterimage experiments. It was proposed that this concentration on highly weighted elements reflected the testing of that schematic map.

When Ss then alternated on the stimulus then again fixations tended to cluster around these elements with similar reporting of each aspect in these weighted areas. When these elements were then removed from the display to see if this affected both the response of figure and the fixation locations then it was found that Ss still tended to fixate the same stimulus regions and similarly reported that aspect in these regions. This was interpreted as demonstrating that the Ss, having established 2 alternate schematic maps for the stimulus in which the weighted stimulus elements were fitted, could then interpret that part of the stimulus, in the absence of the weighted elements, in accordance with the expectations of the schematic map.

The importance of eye movements in figure perception was in shifting selective attention about the stimulus as each schematic map's set of expectations were tested. During alternation between each figural interpretation sometimes an eye movement occurred, immediately before a change of response was made, from one element area to another. However, such movements mainly took place within the same area (1.5^{o}) of an element. In the schematic map formulation a causal eye movement before alternation occurs is not necessarily predicted as alternation is considered to involve a change in selective attention which may occur when an already fixated element is re-interpreted. It was proposed that this result confirmed the schematic map proposal in that sometimes alternation involved the re-interpretation of an already encoded element into the alternate map (when no eye movement between elements occurred) and sometimes a movement between differently weighted elements occurred commensurate with a change of response. Several intervening eye movements were found between each of the responses indicating either aspect. These movements were proposed to reflect the S attempting to switch maps so that there was this period when no clear percept of either figure was readily available. Such intervening movements did play a role in the alternation from one to the other figure as this 'no response' period was always followed by the other aspect response.

7.2. THE MODEL

The following model is proposed to account for the role of eye movements in figure perception as determined by the foregoing research. The model is conceptual making no physiological claims.

It is proposed that any two-dimensional representation of a real-world object can be considered as a constellation of picture elements. These elements are themselves composed of one or more features as discriminated in the display by the observer's feature detecting mechanisms. Each element is defined as representing some part of numerous objects in the real world. Thus each individual element can be interpreted by the observer in several different ways. Each of these possible interpretations can be assigned a weighting representing the likelihood that that element will be interpreted in a particular manner. This weighting depends upon several factors such as the observer's prior experience with real-world objects. The possible interpretations of each individual element are neither infinite nor made in isolation but are limited by the same factors which serve to define the possible ways in which the various elements represent parts of real objects. A two way process is then proposed to exist between the real-world expectations as they are applied to these elements, which themselves are sequentially attended to and abstracted from the display. The elements are both 'fitted' into the expectations and the expectations partly govern the elements sequentially attended to. Norman and Rumelhart (1975) have made a similar proposal calling these two strategies 'bottom-up,' where the processing starts from the stimulus, and 'top-down' where it starts from the schema. This is also essentially what is meant by Hochberg's (1970b) distinction between peripheral search guidance and cognitive search guidance. The importance of this two way process is that the ongoing schematic map can not only be modified by the stimulus information, as in Neisser's (1976) 'perceptual cycle', but on occasions the schematic map can effectively over-ride stimulus data which conflicts with the map expectations.

Each interpretation of the stimulus is governed by a schematic map which functions as an expectancy testing program predicting what will be perceived at various locations in the stimulus. Eye movements about the stimulus function to alter selective attention to different stimulus elements both in accord with expectations from this map and also as a result of current peripheral visual information. Thus eye movements are not solely determined by the schematic map, nor by the stimulus information, but by an 'interplay' between both. In Hochberg's (1968) theory each schematic map is considered to be a sequence of visuo-motor expectancies such that the intention to make an eye movement with a definite expectation is all important. Littman and Becklen (1976) have similarly proposed that eye movements depend on perceptual anticipations rather than acting to initiate a perceptual act. This meaning of schematic map is adhered to here although with experience or with small stimuli these expectations, and accompanying eye movements, may possibly become largely internalised shifts of attention as suggested by Noton and Stark(1971b). The schematic maps must be flexible to allow for the recognition of mirror-image stimuli or for stimuli of different magnification. The expectations of each map are ultimately governed by ecological contingencies i.e. they depend upon the structure of the real world. In another context the role of real-world schemata in the recognition of pictures has been considered by Biederman (1972) and also Biederman,Glass and Stacy (1973). Mandler and Parker (1976) have more recently demonstrated that such schemata affect memory for spatial relations.

The majority of ambiguous and reversible perspective figures are proposed to be represented by two almost equally plausible interpretations, two schematic maps, into which the elements can be fitted. Less plausible interpretations will also exist. For each schematic map, representing the two alternative aspects in these stimuli, the distribution of the element weightings is proposed to be spatially different. This distribution of each set of weightings scross the stimulus can be likened to the contour lines on a map joining areas of equal bias towards one interpretation of the stimulus. For some stimuli the difference in this spatial distribution of bias toward each aspect will be small, whereas in other stimuli it will be more extreme.

For any given fixation point on the stimulus the observer will be able to attend to only specific elements. Other elements and features will be more peripherally viewed and will be more 'globally' analysed by the preattentive processes during that fixation. For example, Biederman, Rabinowitz, Glass and Stacy (1974) have shown that in a single fixation both particular elements and a more global characterisation of the stimulus are extracted by the observer. The immediate response of figure when the observer views the stimulus will depend upon the relative weightings of the elements to which he can attend as they fit into each schematic map. At each fixation position the visual system is considered to apply a secondary weighting process to these elements depending upon how foveally or peripherally they are viewed. This secondary process will depend upon factors such as peripheral visual acuity, so that some elements may not need to be foveally fixated or alternatively elements may be 'screened off' as not being important. The response is proposed to be due largely to the sum of these weightings as they affect each alternate schematic map, with the map chosen by the observer as 'figure' being the 'best-bet' of all this information, which then creates expectations of how subsequently attended elements will be interpreted.

The stimulus area to which the observer can attend in a single fixation is proposed to be not simply that encompassed by the fovea. An essentially dual visual system has been suggested by several researchers with a foveal identifying system and a more diffuse peripheral monitoring and locating system (e.g. Trevarthen,1968; Didday and Arbid, 1975; Mackworth and Morandi, 1967). While generally accepting this distinction it is proposed that the observer can attend to an area larger than the fovea. This area is determined both by stimulus and observer parameters which together serve to effectively widen or narrow this attentive field. Mackworth (1976) has used the term 'useful field of view' to define the area around the fovea from which information is effectively processed. This area is affected by the density of irrelevant items in the display (Mackworth, 1965; Mackworth, 1976). The amount of information being processed by the fovea also affects this 'functional visual field' (Sanders, 1970) such that as the foveal load increases, this field shrinks (Ikeda and Takeuchi, 1975). Experience or training with the stimulus can largely overcome this shrinkage (Engel,1971). Edwards and Goolkasian (1974) demonstrated that, with practice, observers could attend to objects peripherally presented and proposed several 'fields' extending from the fovea to the periphery such that there was a general falling off in recognition, identification and detection performance. Gould (1976) has used a zoom lens analogy to describe how observers can selectively attend to different sized areas of a display.

If the observer is then free to scan the stimulus then both peripheral information and the ongoing schematic map instigated by the first fixation

(Chastain and Burnham, 1975) serve to determine the next fixation location. An eye movement (saccade) will be made to this location with an expectation, dependent upon the schematic map, of interpreting information foveally viewed there. Due to the ballistic nature of saccades an eye movement is made to informative regions(e.g. Baker and Loeb,1973; Antes,1974) as assessed by the peripheral processing during the present fixation (Gould and Dill, 1969). If the information at this fixation confirms or modifies the current map then subsequent eye movements will be made with an appropriate expectation. In the free viewing of such stimuli the observer may make several eye movements before responding. This may reflect the testing of the schematic map over such fixations.

With ambiguous and reversible perspective figures alternation occurs so that a different response of figure is given for the same stimulus. This is due to the current map faltering and an alternate one, representing a different stimulus interpretation, is then undertaken. This alternation may occur because the observer fixates an element which has a low weighting in the current map but a relatively high weighting in the alternate map. It may also be because of some form of local satiation which results in an already encoded element being re-interpreted. Thus in some instances eye movements will be made to an alternate element of the stimulus before a change of response of figure is made and in some cases this change will occur with the observer generally fixating the same element.

A period between responding as either of the two alternate aspects may occur when the current schematic map has been relinquished and the observer is attempting to test the alternate one. This is suggested to be more likely to occur in stimuli in which the high probability areas favouring each aspect are relatively spatially separated.

This model, developed to account for the perception of figure particularly in ambiguous and reversible perspective figures, is largely based on that of Hochberg (1968). It differs from this by proposing that more than two alternative maps can exist for such stimuli and by positing that stimulus parts can be weighted in such maps. In this latter respect it is like Chiang (1976). It further emphasises the comparison process between the ongoing map and the extracted stimulus information in which it is similar to Norman and Rumelhart (1975). The way in which the attended-to information can affect the schema is similar to Neisser's 'perceptual cycle' (1976).

7.3. FUTURE PROPOSALS

The different representations of Borings ambiguous figure (Figure 3.2) demonstrate the various ways in which parts of the picture, which have here been termed elements, can be drawn whilst the overall picture is essentially interpreted in the same manner. In contrast the 'one aspect' versions of the same figure (Figure 3.3) show that certain modifications of these elements does alter the perception of figure. These two extremes illustrate how subtle differences in the picture can affect the investigation of a particular schematic map although they do not show just what changes are either necessary or sufficient to reliably alter the response of figure.

For this reason the experimental work presented here has concentrated upon a simplified line drawing of Boring's ambiguous figure. The use of a line drawing both facilitated the empirical definition of the stimulus elements as well as aiding the afterimage appearance in the first 3 experiments. The proposed concept of stimulus elements does not solely apply to line drawings. The results of the present experiments should then be capable of replication, using these other representations of Boring's figure, to confirm the effect of the removal or addition of the equivalent elements in these pictures upon perception of the ambiguous figure.

The investigation of weighted elements in other ambiguous figures can be examined using the same afterimage technique. This would be relatively straightforward where the ambiguous figure is line-drawn such as the rat-man figure (Figure 2.1). The model proposed to account for the perception of figure in a stimulus applies equally to reversible perspective figures as well as the ambiguous figures. Thus the former should also be capable of examination in a similar fashion. One possible problem with this was shown in Experiment 2 where Ss very readily alternated when reporting the appearance of the positive afterimage of the Necker cube. This ready alternation is proposed to reflect the virtual coincidence of the distributions of the element weightings of each alternate schematic map. Whether this holds for all reversible perspective figures and is one of the factors that distinguishes them from ambiguous figures could also be studied.

On initial presentation of the stimulus the S is proposed to select the 'best' schematic map as a result of selective attention to the available elements. The expectations of this map are then tested in the subsequent fixations. The factors affecting the instigation of each map can be investigated by first ascertaining the relative weightings of stimulus elements towards each aspect with the afterimage technique. Stimuli could then be presented using a partial presentation paradigm where a particular element is first presented followed by the rest of the stimulus. It is hypothesised that the initial presentation of an element weighted more towards one particular aspect (e.g. the YE element in Boring's figure) would be more likely to lead to that aspect being reported.

The relative contribution of foveal and peripheral vision to the schematic map could be examined by using techniques whereby only one or other type of vision is available to the S. This can be achieved by using the S's own eye movements in a yoked-feedback fashion to control the amount of the display visible at any instant.

Another approach is to investigate the eye movement patterns that occur with the development of the schematic map from the naive first presentation, when the S possibly first tries to fit other alternate schematic maps to the stimulus, to later trials when the S more readily instigates the appropriate map. This approach would concentrate upon the first few eye movements made before the S responds. It is hypothesised that on the initial naive presentation the eye movement patterns may appear relatively random as a result of the initial testing of several possible schematic maps. On later trials the patterns would be more systematic (e.g. Markovian or even a scanpath).

The present eye movement experiment found an intervening no response period between times when the S was reporting either aspect. This deserves further investigation to see if it is a function of the response procedure used - this is proposed not to be the case. Other researchers have used response techniques which permit such 'either aspect' responses (c.f. section 2.4.2) but there is little evidence in the literature of the popularity of this response as found here in Experiment 6. Whether this response declines with prolonged practice on the stimulus or is a characteristic of ambiguous figures which possibly distinguishes them from reversible perspective figures is also a topic for future work.

7.4 SUMMARY

In this chapter the various conclusions reached in the previous experiments are brought together and then a model proposed to account for the role of eye movements in figure perception. It is argued that the eye movements of a S reflect the testing of a schematic map which is instigated by the available stimulus information at any given fixation position. The schematic map in interaction with current foveal and peripheral vision then leads to other fixations being made with an expectation of interpreting the stimulus in a particular fashion. Figure perception is a result of this process. Finally some suggestions for future work are outlined.

A P P E N D I C E S

FIXATION POSITION	SUBJECT'S RESPONSES																			
	MALE										FEMALE									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	0	1	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1
3	1	0	0	1	0	1	1	1	0	0	1	1	0	1	1	0	1	0	1	0
4	1	1	0	0	1	1	1	1	1	1	1	1	0	1	1	0	1	0	1	1
5	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	0	0	1	0	1	0	0	0	0	1	1	0	1	0	0	0	1	1	0	1
7	0	1	1	0	0	0	1	0	0	1	1	1	0	0	0	0	1	1	1	0
8	1	0	0	0	1	0	1	0	0	1	0	0	0	0	1	0	1	0	1	0
9	1	0	0	1	0	1	0	1	0	0	0	0	0	1	1	0	0	0	0	0
10	0	1	0	0	0	1	0	0	0	0	0	1	1	1	1	0	1	0	0	0
11	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
12	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0
13	1	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1	0	0	0
14	1	1	0	1	1	0	0	0	0	0	0	1	0	1	0	0	1	1	0	0
15	1	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0

1 = Young Woman Response
0 = Old Woman Response

<u>Appendix A</u> <u>Figure A.1</u> Individual responses of the 10 male and 10 female subjects for each fixation position used in Experiment 1.

	FIXATION POSITION 2				FIXATION POSITION 7			
	STIMULUS				STIMULUS			
SUBJECTS	A	B	C	D	A	B	C	D
1	1	1	1	1	1	1	0	0
2	0	1	1	0	0	1	0	0
3	1	1	0	1	1	0	0	0
4	1	1	1	1	1	1	0	1
5	0	1	1	0	1	0	1	1
6	1	1	1	1	0	0	0	1
7	1	1	1	1	1	1	0	1
8	1	1	0	1	1	0	0	0
9	1	1	1	1	1	1	0	0
10	1	1	1	1	1	1	1	0
11	1	1	1	0	1	1	0	0
12	1	1	0	1	1	1	1	1
13	1	1	1	0	0	0	1	0
14	1	1	0	0	1	0	1	0
15	1	1	0	1	0	0	0	0
16	1	1	0	1	1	1	0	0
17	1	1	0	1	0	0	0	0
18	0	1	1	1	0	0	0	0
19	1	1	0	0	1	0	0	1
20	0	1	1	1	1	0	0	0
TOTALS	16	20	12	14	14	9	5	6

Figure A.2 Individual responses obtained for the 2 fixation positions which were used with the 4 stimuli in Experiment 2.

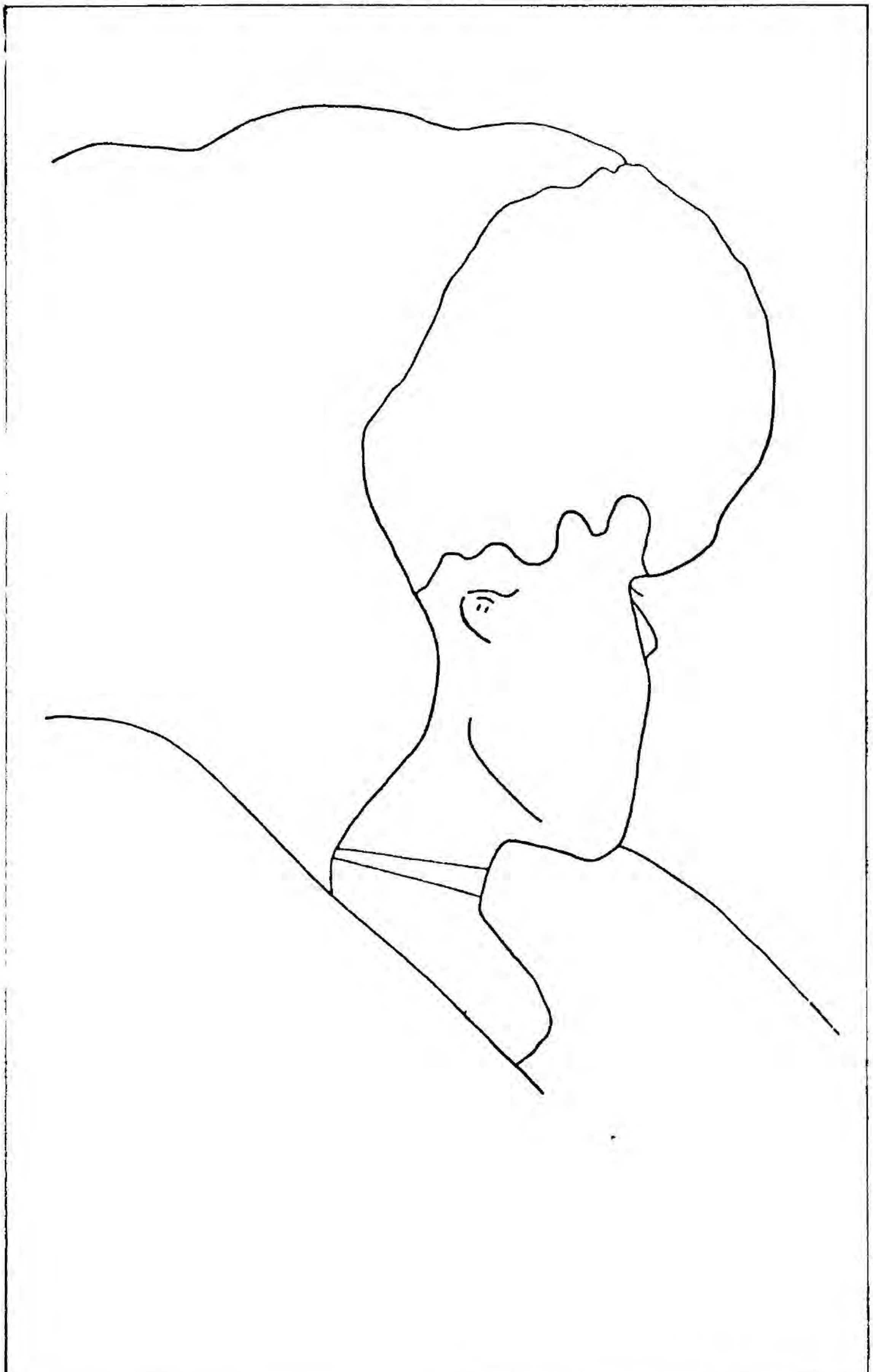
	FIXATION POSITION 2															
	STIMULUS															
SUBJECTS	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	1	1	1	0	1	1	0	0	1	1	0	0	1	1	1	1
2	1	0	1	1	1	1	1	1	0	0	1	1	0	0	1	1
3	1	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0
4	1	1	0	1	1	0	1	0	0	1	1	1	1	0	0	1
5	1	1	0	0	1	1	1	0	1	0	0	1	1	1	1	0
6	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0
9	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0
10	0	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1
11	1	0	1	0	1	1	1	1	0	1	0	0	1	1	1	0
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
15	1	1	1	0	1	1	1	1	1	1	1	1	0	1	0	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
17	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
18	1	1	0	1	1	0	1	0	0	0	0	1	1	0	1	0
19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
20	0	1	1	0	1	1	1	1	1	0	1	1	1	0	0	1
TOTALS	18	18	16	14	19	18	18	13	16	16	15	17	17	15	14	11

Figure A.3 Individual responses obtained for each stimulus at fixation position 2 in Experiment 3.

	FIXATION POSITION 7															
	STIMULUS															
SUBJECTS	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	1	1	0	0	1	1	0	0	1	1	0	1	1	1	0	0
2	0	1	0	0	1	1	1	1	0	1	0	0	1	1	0	0
3	1	1	0	1	0	1	0	1	0	0	0	1	0	0	0	1
4	1	1	0	0	1	1	0	0	1	1	0	0	1	0	0	0
5	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
6	0	0	1	0	0	0	0	1	0	1	0	0	0	1	0	0
7	1	1	0	1	1	1	0	0	0	1	0	0	1	1	1	0
8	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0
9	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
10	1	0	0	0	0	1	1	0	1	1	0	0	0	1	0	0
11	0	1	0	1	1	1	0	0	1	1	0	0	0	1	0	0
12	1	1	0	0	1	1	0	1	1	1	0	0	0	1	0	0
13	0	1	0	1	1	1	0	1	1	1	0	1	1	1	0	0
14	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
15	0	0	0	1	1	1	1	0	1	1	0	0	1	0	0	1
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0
18	0	0	0	0	1	1	1	0	1	1	0	1	0	1	1	1
19	0	0	0	0	1	1	0	0	0	1	0	0	0	1	0	0
20	0	0	0	1	0	1	1	0	1	1	1	1	1	1	1	0
TOTALS	8	11	1	7	12	14	5	6	11	15	1	6	7	11	4	3

Figure A.3(contd.) Individual responses obtained for each stimulus at fixation position 7 in Experiment 3.

APPENDIX B An example of the subjects' response sheets used in Experiment 5 .



OLD WOMAN ______________________________ YOUNG WOMAN

APPENDIX C The full Analysis of Variance summary table for Experiment 5.

The various parameters are listed in the 'source' column as follows:-

	Level 1	Level 2
Between Ss factors(B)		
Age (B1)	Young	Old
Photograph direction (B2)	Right	Left
Within Ss factors (W)		
Stimulus direction(W1)	Right	Left
YE element(W2)	Absent	Present
E/EC element (W3)	Absent	Present
CL element (W4)	Absent	Present
M element (W5)	Absent	Present

SOURCE	DF	SS	MS	F	PROB
SUBJ	51	269369.1635			
B1	1	936.0000	936.0000	0.1715	0.68363
B2	1	320.2524	320.2524	0.0587	0.80478
B12	1	6130.7909	6130.7909	1.1233	0.29473
EB12	48	265082.1202	5457.9608		
W1	1	918.0805	918.0805	1.6984	0.19592
W1B1	1	106.0096	106.0096	0.1961	0.66397
W1B2	1	2.3101	2.3101	0.0043	0.94808
W1B12	1	703.5601	703.5601	1.3015	0.25853
EW1B12	48	25947.2037	540.5084		
W2	1	137279.4447	137279.4447	31.6595	0.00002
W2B1	1	1050.2909	1050.2909	0.2422	0.62342
W2B2	1	2215.3846	2215.3846	0.5109	0.51494
W2B12	1	1191.3846	1191.3846	0.2748	0.60879
EW2B12	48	208133.8702	4336.1223		
W3	1	22361.7788	22361.7788	8.2895	0.00604
W3B1	1	8227.1635	8227.1635	3.0498	0.08349
W3B2	1	632.6178	632.6178	0.2345	0.63578
W3B12	1	32.9062	32.9062	0.0122	0.90875
EW3B12	48	129485.0337	2697.6049		
W4	1	4472.3462	4472.3462	4.3188	0.04060
W4B1	1	264.9615	264.9615	0.2559	0.62117
W4B2	1	187.1178	187.1178	0.1807	0.67611
W4B12	1	0.6947	0.6947	0.0007	0.97769
EW4B12	48	49706.1298	1035.5444		
W5	1	39624.0385	39624.0385	23.0956	0.00008
W5B1	1	79.6250	79.6250	0.0464	0.82481
W5B2	1	4031.3101	4031.3101	2.3497	0.12810
W5B12	1	141.9447	141.9447	0.0827	0.77182
EW5B12	48	82351.4567	1715.6553		
W12	1	363.7524	363.7524	0.4622	0.50682
W12B1	1	276.2524	276.2524	0.3510	0.56323
W12B2	1	690.6154	690.6154	0.8775	0.64395
W12B12	1	906.2404	906.2404	1.1514	0.28866
EW12B12	48	37778.7644	787.0576		
W13	1	1225.4712	1225.4712	1.1573	0.28735
W13B1	1	2951.1154	2951.1154	2.7869	0.09777
W13B2	1	1363.0024	1363.0024	1.2871	0.26123
W13B12	1	382.6947	382.6947	0.3614	0.55749
EW13B12	48	50828.9063	1058.9368		
W14	1	972.3462	972.3462	1.4306	0.23576
W14B1	1	3004.6250	3004.6250	4.4208	0.03842
W14B2	1	54.8101	54.8101	0.0806	0.77444
W14B12	1	334.4447	334.4447	0.4921	0.50669
EW14B12	48	32623.5240	679.6568		
W15	1	737.7788	737.7788	0.9086	0.65270
W15B1	1	461.1635	461.1635	0.5679	0.53880
W15B2	1	214.9062	214.9062	0.2647	0.61534
W15B12	1	91.4063	91.4063	0.1126	0.73799
EW15B12	48	38975.1202	811.9817		
W23	1	85.8678	85.8678	0.0696	0.78896
W23B1	1	1319.9062	1319.9062	1.0701	0.30679
W23B2	1	912.1538	912.1538	0.7395	0.60155
W23B12	1	436.2404	436.2404	0.3537	0.56175
EW23B12	48	59207.2007	1233.4835		
W24	1	28.5601	28.5601	0.0339	0.84897
W24B1	1	386.5409	386.5409	0.4582	0.50806
W24B2	1	1085.5385	1085.5385	1.2868	0.26130
W24B12	1	436.2404	436.2404	0.5171	0.51701
EW24B12	48	40493.2452	843.6093		

W25	1	1765,5024	1765,5024	2,5760	0,11123
W25B1	1	43,8101	43,8101	0,0639	0,79699
W25B2	1	180,4712	180,4712	0,2633	0,61622
W25B12	1	86,7788	86,7788	0,1266	0,72383
EW25B12	48	32896,9375	685,3529		
W34	1	294,4712	294,4712	0,2698	0,61203
W34B1	1	753,8462	753,8462	0,6906	0,58491
W34B2	1	12,1178	12,1178	0,0111	0,91303
W34B12	1	209,1947	209,1947	0,1916	0,66744
EW34B12	48	52398,8702	1091,6431		
W35	1	22,1538	22,1538	0,0137	0,90338
W35B1	1	1929,8462	1929,8462	1,1895	0,28057
W35B2	1	4,0409	4,0409	0,0025	0,95933
W35B12	1	740,4447	740,4447	0,4564	0,50950
EW35B12	48	77876,1394	1622,4196		
W45	1	1736,7788	1736,7788	3,2668	0,07347
W45B1	1	63,0865	63,0865	0,1187	0,73174
W45B2	1	43,8101	43,8101	0,0824	0,77223
W45B12	1	1256,5601	1256,5601	2,3635	0,12699
EW45B12	48	25519,1394	531,6487		
W123	1	276,2524	276,2524	0,4403	0,51712
W123B1	1	2229,2524	2229,2524	3,5528	0,06226
W123B2	1	517,5385	517,5385	0,8248	0,62850
W123B12	1	2700,9615	2700,9615	4,3046	0,04091
EW123B12	48	30117,6702	627,4556		
W124	1	688,0409	688,0409	1,1323	0,29275
W124B1	1	273,0024	273,0024	0,4493	0,51284
W124B2	1	690,6154	690,6154	1,1365	0,29182
W124B12	1	2,4615	2,4615	0,0041	0,94811
EW124B12	48	29167,2548	607,6511		
W125	1	276,2524	276,2524	0.3553	0,56083
W125B1	1	137,3101	137,3101	0,1766	0,67942
W125B2	1	581,8846	581,8846	0,7484	0,60449
W125B12	1	13,1635	13,1635	0,0169	0,89234
EW125B12	48	37318,6394	777,4717		
W134	1	287,7788	287,7788	0,3059	0,58938
W134B1	1	3852,7788	3852,7788	4,0955	0,04588
W134B2	1	406,0601	406,0601	0,4316	0,52128
W134B12	1	2229,2524	2229,2524	2,3697	0,12650
EW134B12	48	45154,8798	940,7267		
W135	1	255,4712	255,4712	0,4594	0,50809
W135B1	1	138,4615	138,4615	0,2490	0,62579
W135B2	1	10,7909	10,7909	0,0194	0,88477
W135B12	1	2210,7716	2210,7716	3,9757	0,04903
EW135B12	48	26691,3798	556,0704		
W145	1	240,0385	240,0385	0,2809	0,60486
W145B1	1	110,0865	110,0865	0,1288	0,72168
W145B2	1	1018,7524	1018,7524	1,1923	0,28000
W145B12	1	939,0024	939,0024	1,0989	0,30017
EW145B12	48	41014,4952	854,4686		
W234	1	263,3678	263,3678	0,4144	0,52977
W234B1	1	109,0601	109,0601	0,1716	0,68353
W234B2	1	2206,1635	2206,1635	3,4715	0,06523
W234B12	1	388,4712	388,4712	0,6113	0,55587
EW234B12	48	30504,0625	635,5013		
W235	1	141,9447	141,9447	0,2517	0,62398
W235B1	1	273,0024	273,0024	0,4840	0,50312
W235B2	1	1295,0865	1295,0865	2,2963	0,13250
W235B12	1	234,0000	234,0000	0,4149	0,52953
EW235B12	48	27071,9663	563,9993		

W245	1	4233,0024	4233,0024	4,6041	0,03482
W245B1	1	151,4447	151,4447	0,1647	0,68930
W245B2	1	2299,2404	2299,2404	2,5008	0,11654
W245B12	1	1861,5385	1861,5385	2,0247	0,15774
EW245B12	48	44131,0240	919,3963		
W345	1	24,0385	24,0385	0,0243	0,87125
W345B1	1	118,4712	118,4712	0,1198	0,73057
W345B2	1	632,6178	632,6178	0,6398	0,56664
W345B12	1	87,6947	87,6947	0,0887	0,76456
EW345B12	48	47456,3029	988,7146		
W1234	1	430,1178	430,1178	0,5021	0,51108
W1234B1	1	891,5409	891,5409	1,0406	0,31373
W1234B2	1	207,7788	207,7788	0,2425	0,63021
W1234B12	1	58,5000	58,5000	0,0663	0,79880
EW1234B12	48	41122,6875	856,7227		
W1235	1	263,3678	263,3678	0,3116	0,58596
W1235B1	1	1,5024	1,5024	0,0018	0,96547
W1235B2	1	1218,6154	1218,6154	1,4418	0,23392
W1235B12	1	465,3846	465,3846	0,5506	0,53172
EW1235B12	48	40570,6298	845,2215		
W1245	1	1,5024	1,5024	0,0015	0,96832
W1245B1	1	414,0024	414,0024	0,4081	0,53295
W1245B2	1	1477,5385	1477,5385	1,4564	0,23152
W1245B12	1	22,1538	22,1538	0,0218	0,87785
EW1245B12	48	48696,3029	1014,5063		
W1345	1	18,1635	13,1635	0,0164	0,89406
W1345B1	1	249,2404	249,2404	0,3104	0,58668
W1345B2	1	3195,6947	3195,6947	3,9799	0,04892
W1345B12	1	257,0409	257,0409	0,3201	0,58091
EW1345B12	48	38542,2356	802,9632		
W2345	1	40,0024	40,0024	0,0794	0,77602
W2345B1	1	289,4447	289,4447	0,5745	0,54144
W2345B2	1	1538,4615	1538,4615	3,0537	0,08330
W2345B12	1	157,5385	157,5385	0,3127	0,58531
EW2345B12	48	24182,8029	503,8084		
W12345	1	168,8101	168,8101	0,3540	0,56158
W12345B1	1	139,6178	139,6178	0,2928	0,59744
W12345B2	1	1819,4712	1819,4712	3,8151	0,05364
W12345B12	1	775,5385	775,5385	1,6262	0,20580
EW12345B12	48	22891,8125	476,9128		
W	1612	1018746,7500			

TSQ/N= 4362498,0065 N= 1664 SSI= 2088115,9135

APPENDIX D Derivation of the correction constants.

If x, y are the observed co-ordinates of a point whose real co-ordinates are z, t then the calculated co-ordinates (z', t') are given by:-

$$z' = Ax + By + C \quad \ldots.(1)$$

$$t' = Dx + Ey + F \quad \ldots.(2)$$

where A,B,C,D,E, and F are constants.

By the method of least squares the best fit to the data is when the sum of the squared errors is minimised.

This sum is given by:-

$$\Sigma = \Sigma\{(z-z')^2 + (t-t')^2\}$$

substituting from (1) and (2)

$$\Sigma = \Sigma(z-Ax-By-C)^2 + \Sigma(t-Dx-Ey-F)^2$$

Minimising the partial differentials:

$$\frac{\delta\Sigma}{\delta A} = 2\ \Sigma(z-Ax-By-C)(-x) = 2\{A\Sigma x^2 + B\Sigma xy + C\Sigma x - \Sigma xz\} = 0 \quad (3)$$

$$\frac{\delta\Sigma}{\delta B} = 2\ \Sigma(z-Ax-By-C)(-y) = 2\{A\Sigma xy + B\Sigma y^2 + C\Sigma y - \Sigma yz\} = 0 \quad (4)$$

$$\frac{\delta\Sigma}{\delta C} = 2\ \Sigma(z-Ax-By-C)(-1) = 2\{A\Sigma x + B\Sigma y + NC - \Sigma z\} = 0 \quad (5)$$

where N is the number of points considered.

$$\frac{\delta\Sigma}{\delta D} = 2\ \Sigma(t-Dx-Ey-F)(-x) = 2\{D\Sigma x^2 + E\Sigma xy + F\Sigma x - \Sigma xt\} = 0 \quad (6)$$

$$\frac{\delta\Sigma}{\delta E} = 2\ \Sigma(t-Dx-Ey-F)(-y) = 2\{D\Sigma xy + E\Sigma y^2 + F\Sigma y - \Sigma yt\} = 0 \quad (7)$$

$$\frac{\delta\Sigma}{\delta F} = 2\ \Sigma(t-Dx-Ey-F)(-1) = 2\{D\Sigma x + E\Sigma y + NF - \Sigma t\} = 0 \quad (8)$$

Using matrices to solve the simultaneous equations (3) (4) and (5).

$$\frac{A}{\begin{vmatrix} \Sigma xy & \Sigma x & -\Sigma xz \\ \Sigma y^2 & \Sigma y & -\Sigma yz \\ \Sigma y & N & -\Sigma z \end{vmatrix}} = \frac{B}{\begin{vmatrix} \Sigma x^2 & \Sigma x & -\Sigma xz \\ \Sigma xy & \Sigma y & \Sigma yz \\ \Sigma x & N & \Sigma z \end{vmatrix}} = \frac{C}{\begin{vmatrix} \Sigma x^2 & \Sigma xy & \Sigma xz \\ \Sigma xy & \Sigma y^2 & \Sigma yz \\ \Sigma x & \Sigma y & \Sigma z \end{vmatrix}} = \frac{-1}{\begin{vmatrix} \Sigma x^2 & \Sigma xy & \Sigma x \\ \Sigma xy & \Sigma y^2 & \Sigma y \\ \Sigma x & \Sigma y & N \end{vmatrix}}$$

Then:

$A = \{\Sigma xy\ (N\Sigma yz - \Sigma y\ \Sigma z) - \Sigma x(\Sigma y\Sigma yz - \Sigma z\Sigma y^2) - \Sigma xz\ (N\Sigma y^2 - (\Sigma y)^2)\}\ /DEN\ 1$

$B = -\{\Sigma x^2\ (N\Sigma yz - \Sigma y\ \Sigma z) - \Sigma x(\Sigma x\Sigma yz - \Sigma z\Sigma xy) - \Sigma xz\ (N\Sigma xy - \Sigma x\ \Sigma y)\}\ /DEN\ 1$

$C = \{\Sigma x^2\ (\Sigma y\ \Sigma yz - \Sigma z\ \Sigma y^2) - \Sigma xy\ (\Sigma x\ \Sigma yz - \Sigma z\Sigma xy) - \Sigma xz\ (\Sigma y\Sigma xy - \Sigma x\Sigma y^2)\}\ /DEN\ 1$

where the denominator DEN 1 is given by:

$DEN\ 1 = -\{\Sigma x^2\ (N\Sigma y^2 - (\Sigma y)^2) - \Sigma xy\ (N\Sigma xy - \Sigma x\Sigma y) + \Sigma x\ (\Sigma xy\ \Sigma y - \Sigma x\ \Sigma y^2)\}$

Similarly solving the simultaneous equations (6), (7) and (8):

$$\frac{D}{\begin{vmatrix} \Sigma xy & \Sigma x & -\Sigma xt \\ \Sigma y^2 & \Sigma y & -\Sigma yt \\ \Sigma y & N & -\Sigma t \end{vmatrix}} = \frac{E}{\begin{vmatrix} \Sigma x^2 & \Sigma x & -\Sigma xt \\ \Sigma xy & \Sigma y & \Sigma yt \\ \Sigma x & N & \Sigma t \end{vmatrix}} = \frac{F}{-\begin{vmatrix} \Sigma x^2 & \Sigma xy & -\Sigma xt \\ \Sigma xy & \Sigma y^2 & -\Sigma yt \\ \Sigma x & \Sigma y & \Sigma t \end{vmatrix}} = \frac{-1}{\begin{vmatrix} \Sigma x^2 & \Sigma xy & \Sigma x \\ \Sigma xy & \Sigma y^2 & \Sigma y \\ \Sigma x & \Sigma y & N \end{vmatrix}}$$

then

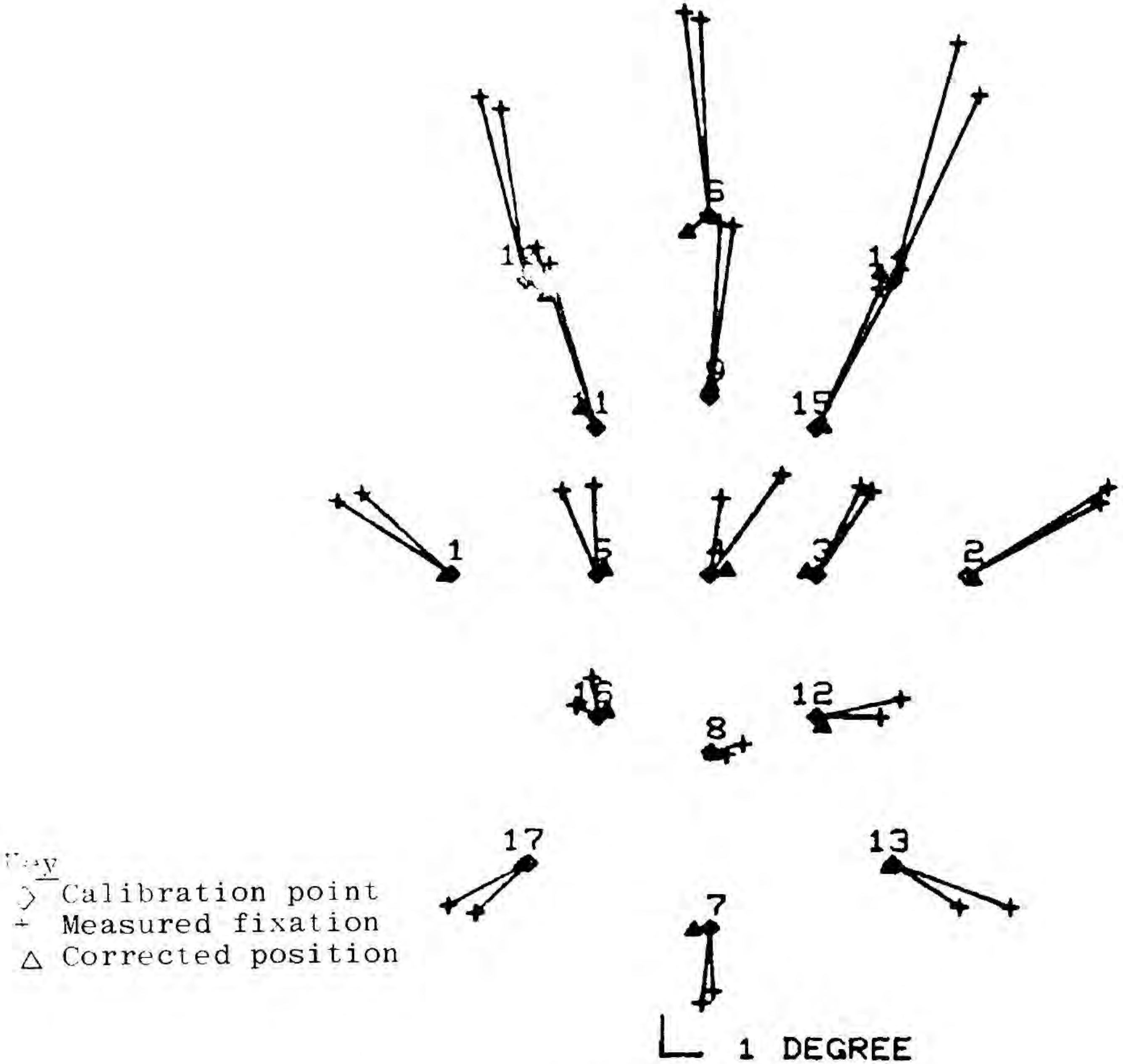
$D = \{\Sigma xy\ (N\ \Sigma yt - \Sigma y\ \Sigma t) - \Sigma x\ (\Sigma y\Sigma yt - \Sigma y^2\Sigma t) - \Sigma xt\ (N\Sigma y^2 - (\Sigma y)^2)\}/DEN\ 2$

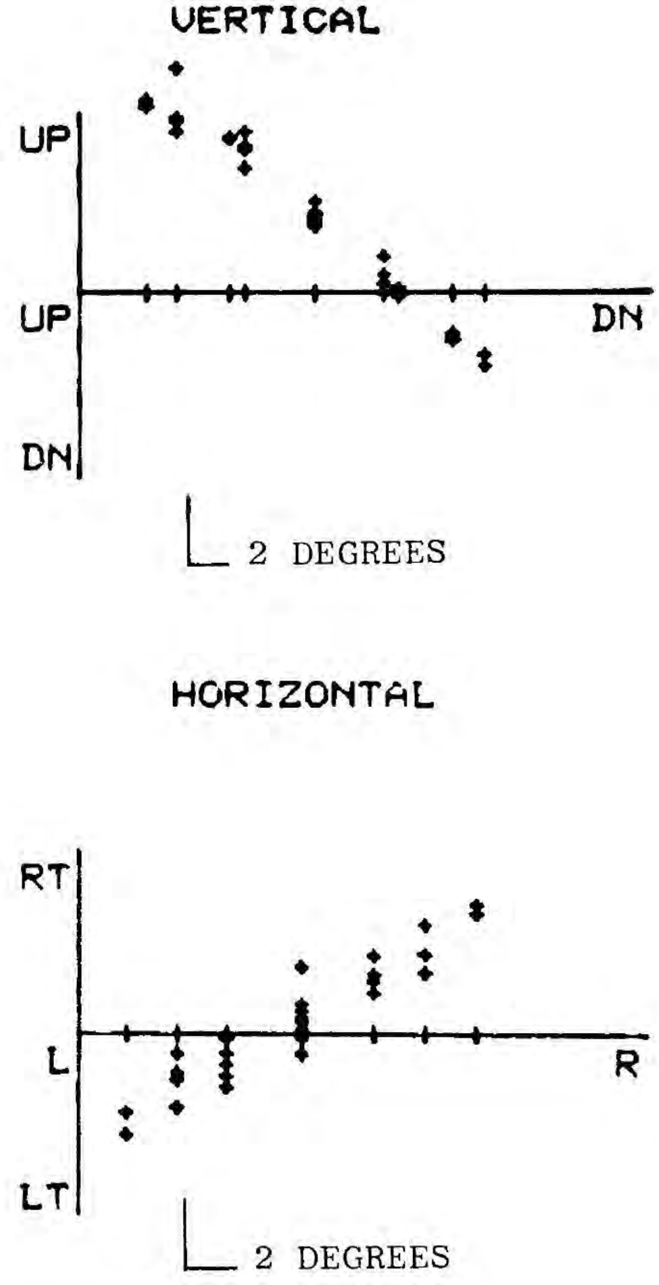
$E = -\{\Sigma x^2\ (N\Sigma yt - \Sigma y\ \Sigma t) - \Sigma x\ (\Sigma x\ \Sigma yt - \Sigma xy\ \Sigma t) - \Sigma xt\ (N\Sigma xy - \Sigma x\ \Sigma y)\}/DEN\ 2$

$F = \{\Sigma x^2\ (\Sigma y\ \Sigma yt - \Sigma y^2\ \Sigma t) - \Sigma xy\ (\Sigma x\ \Sigma yt - \Sigma xy\ \Sigma t) - \Sigma xt\ (\Sigma xy\Sigma y - \Sigma x\ \Sigma y^2)\}/DEN\ 2$

where the denominator DEN 2 is given by:

$DEN\ 2 = -\{\Sigma x^2\ (N\Sigma y^2 - (\Sigma y)^2) - \Sigma xy\ (N\Sigma xy - \Sigma x\Sigma y) + \Sigma x\ (\Sigma xy\Sigma y - \Sigma x\ \Sigma y^2)\}$



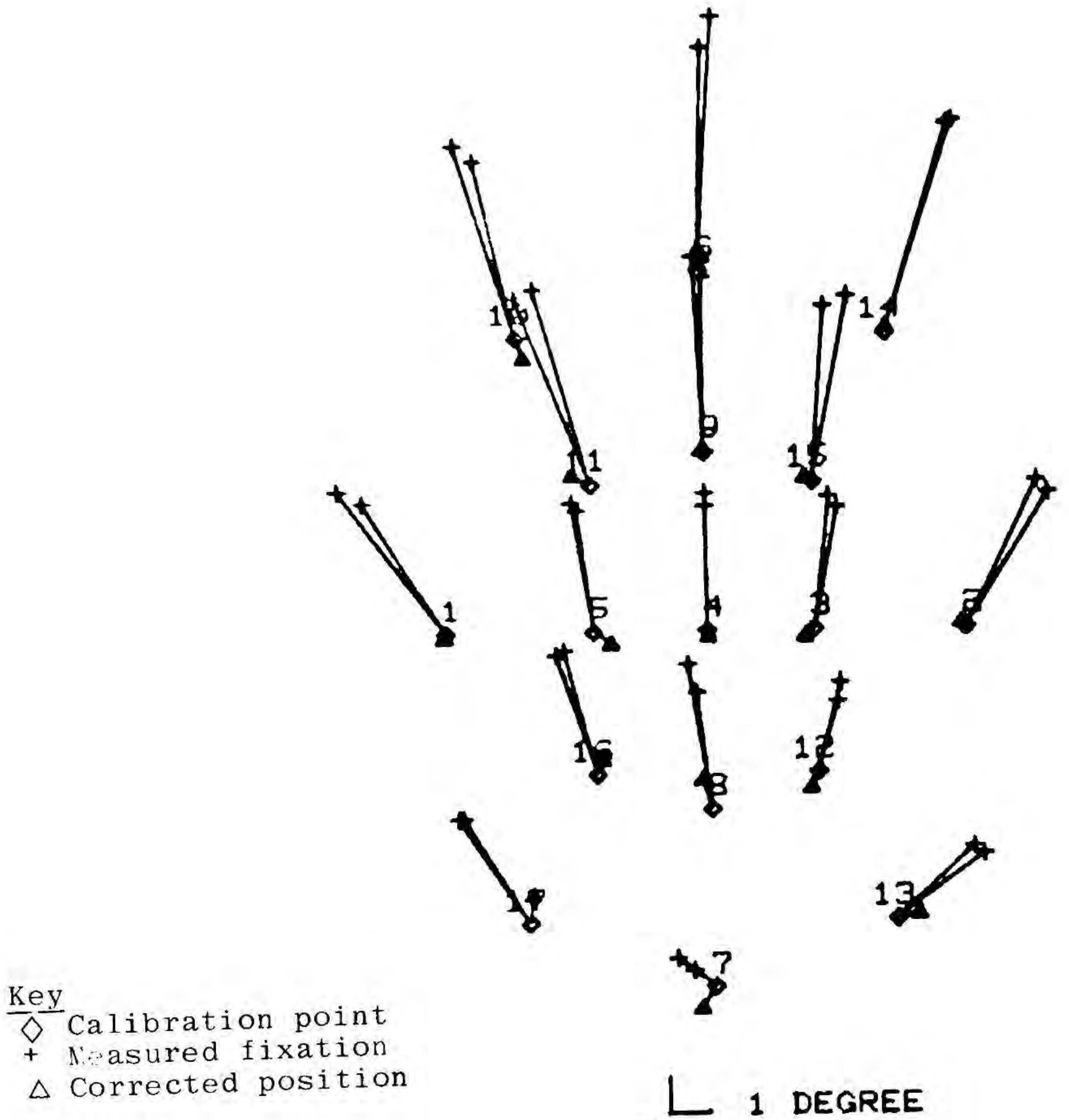


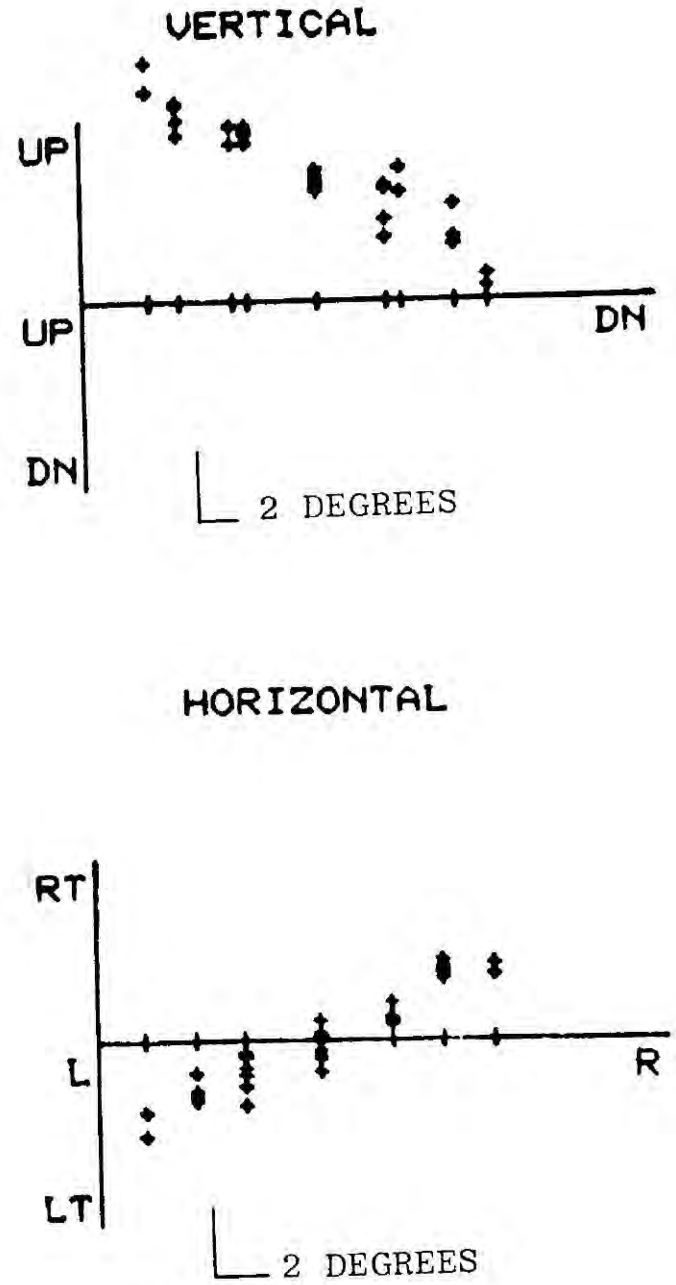
DISPARITY GRAPHS

MEAN ERROR=0.31^{o}

Calibration data for subject A on the second trial.

APPENDIX E The second calibration data.

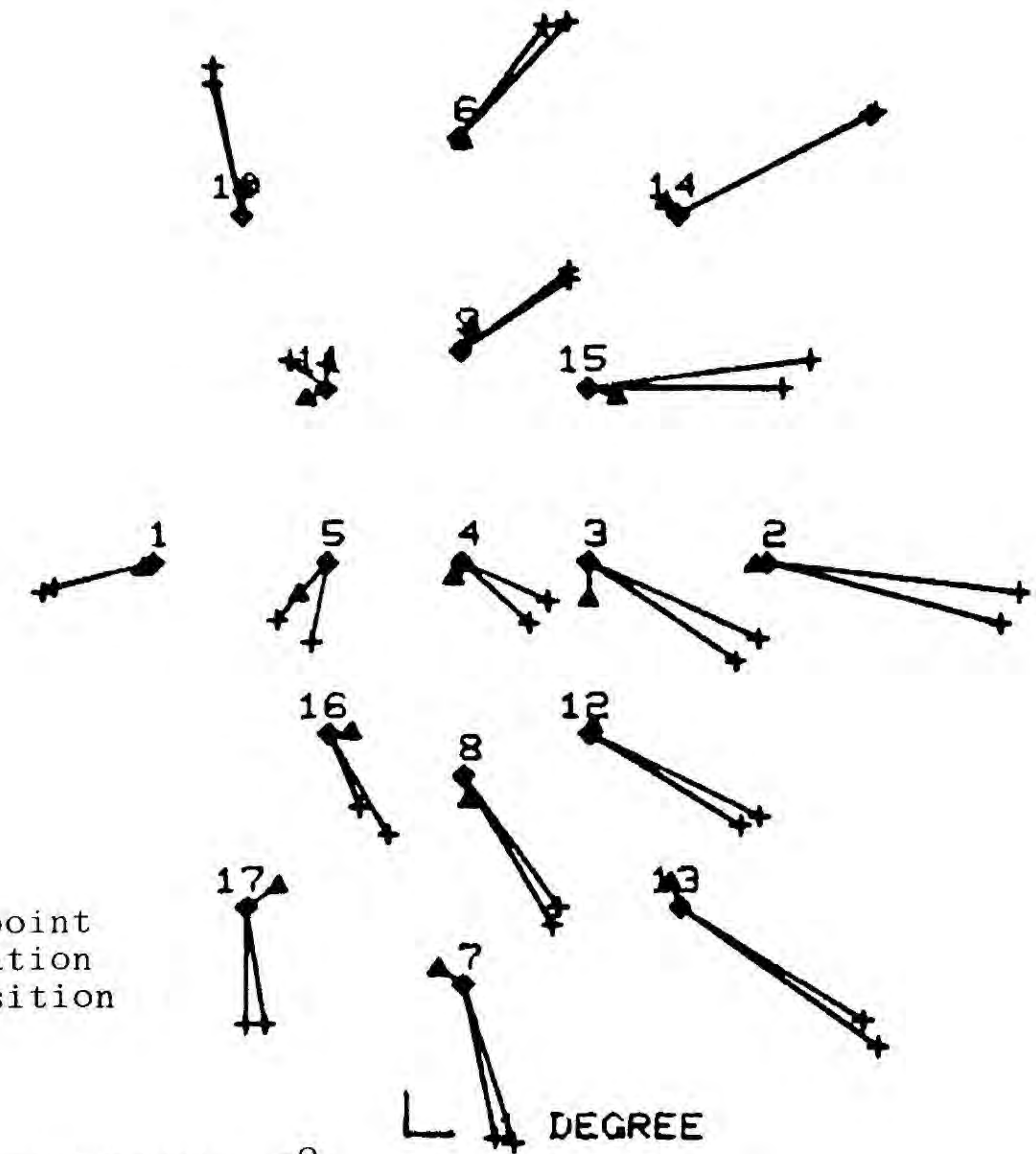




DISPARITY GRAPHS

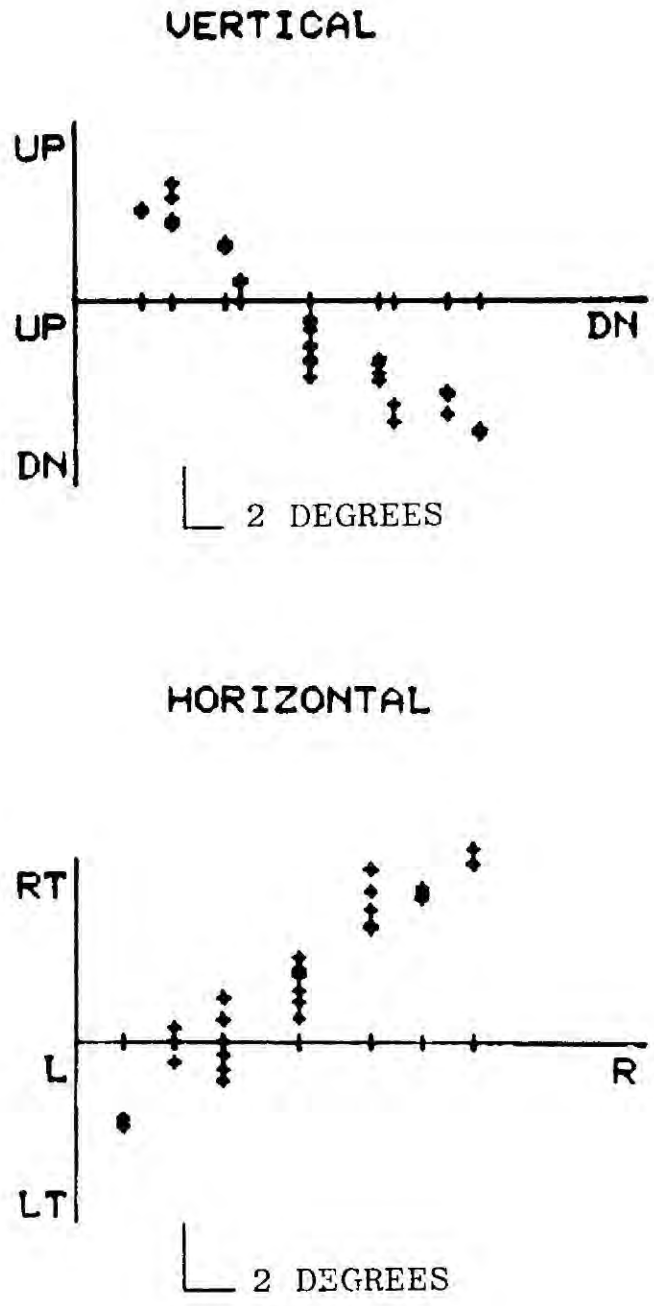
MEAN ERROR=0.39°

Calibration data for subject B on the second tri·



Key
◇ Calibration point
+ Measured fixation
△ Corrected position

MEAN ERROR=0.5°



DISPARITY GRAPHS

Calibration data for subject C on the second trial.

APPENDIX F

The Figures in this Appendix show the fixation locations of the Ss in the 6 alternation conditions of Experiment 6 and also the corresponding graphs of saccade lengths.

The Spatial Plots

The following symbols are used to indicate the response state:-

□ NO

◇ ST

▪ NR

X YW

+ OW

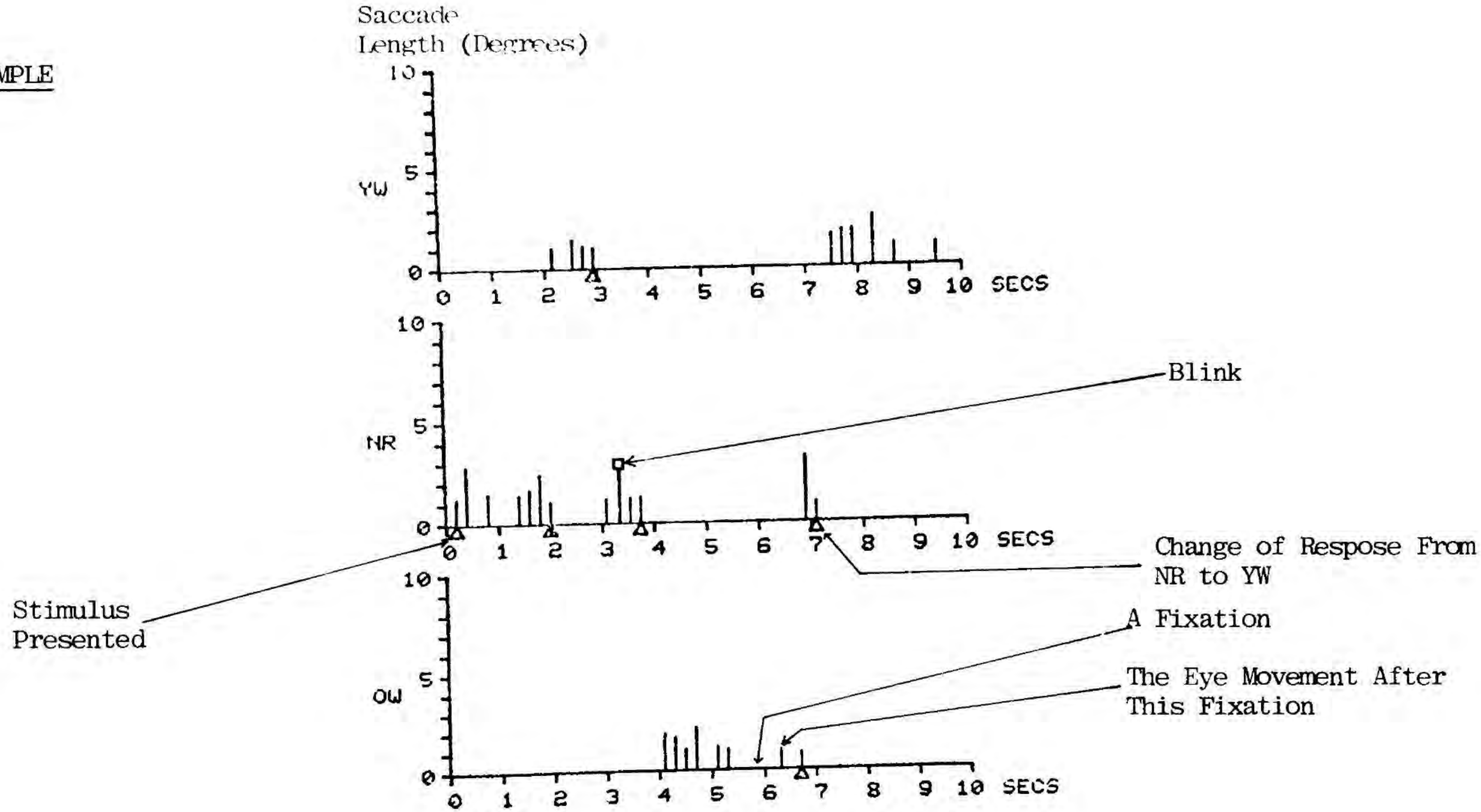
The circled symbol is the fixation position before the S's first response of YW or OW. The lines indicate the saccades between fixation locations which were accompanied by a change in the S's response. A blink during this change of response is shown by a dotted line.

The Graphs

For each figure the S's response of YW, OW or NR is shown plotted over the 10s period. The vertical axis of each response state represents the saccade length of each eye movement which occurred whilst the S was making that response. Each fixation is represented by a period of time on the horizontal axis followed by an eye movement. The eye movement between a change of response is indicated by a triangle at the base of that saccade. An eye movement during a blink is indicated by a square at the top of the corresponding 'saccade length'.

An example is first given to clarify this.

EXAMPLE



Saccade
Length (Degrees)
YW
NR
OW
SECS
Blink
Change of Respose From
NR to YW
A Fixation
The Eye Movement After
This Fixation
Stimulus
Presented

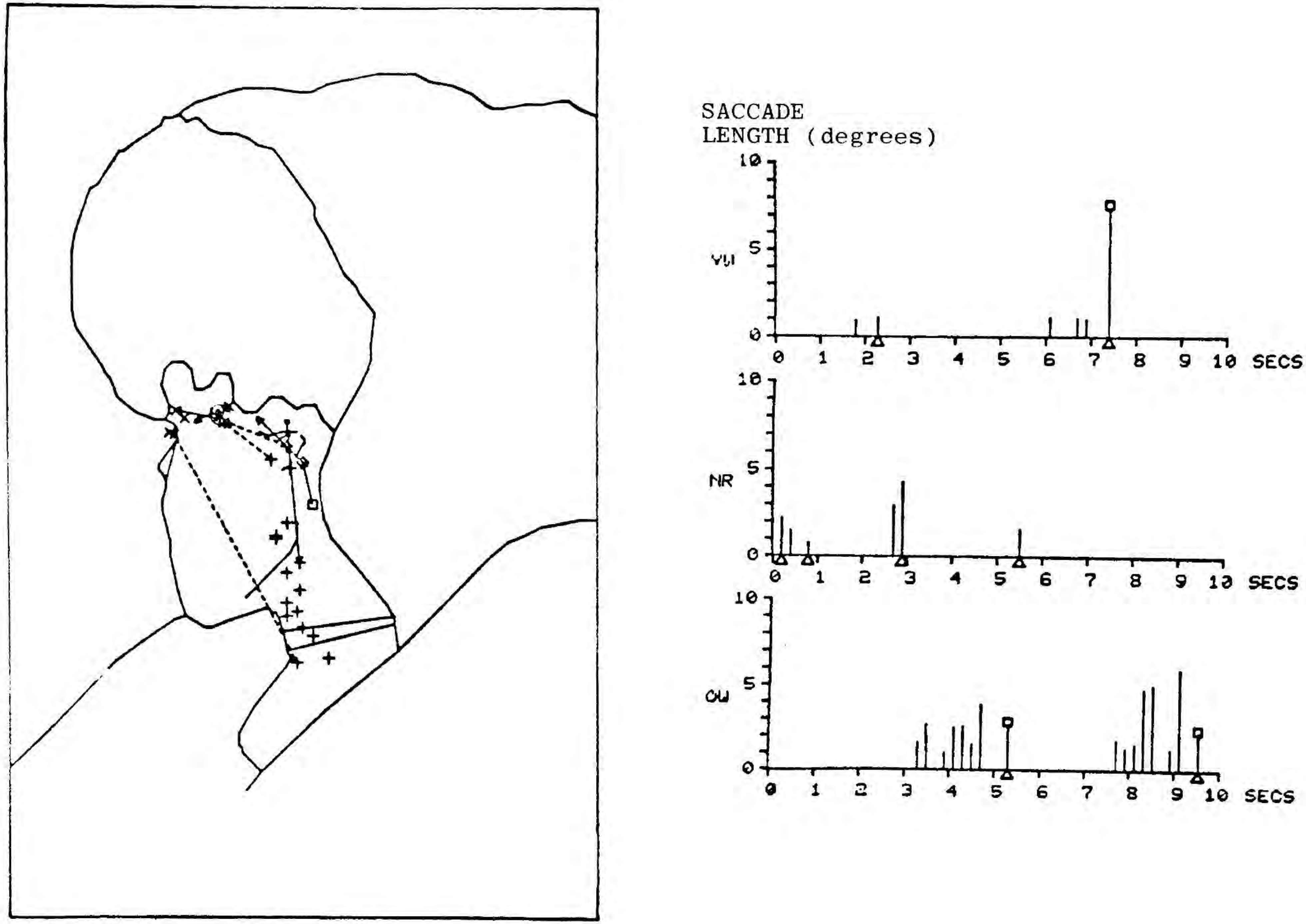


Figure F.1(a) All elements present. Subject SW.

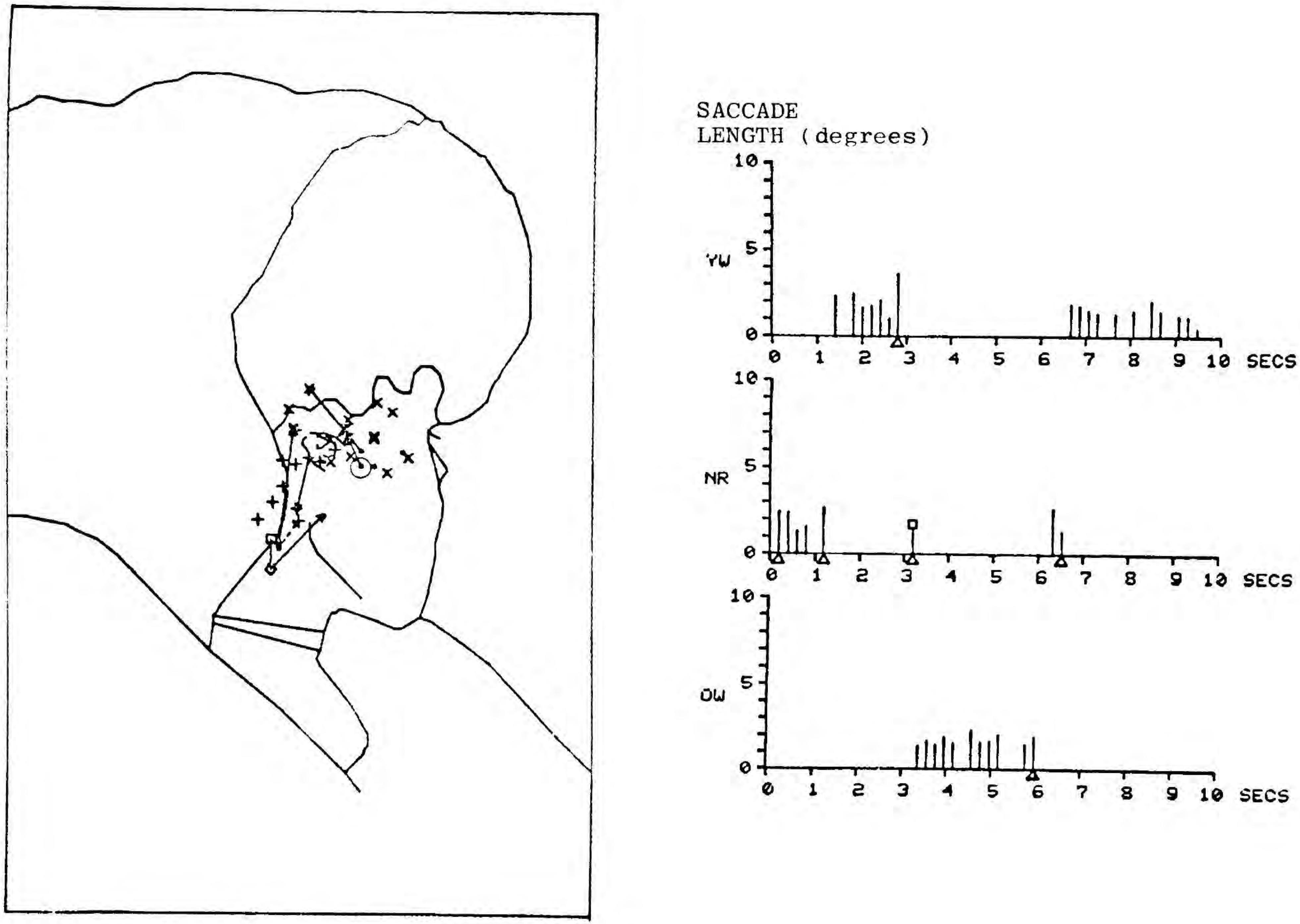


Figure F.1(b) All elements present. Subject AS.

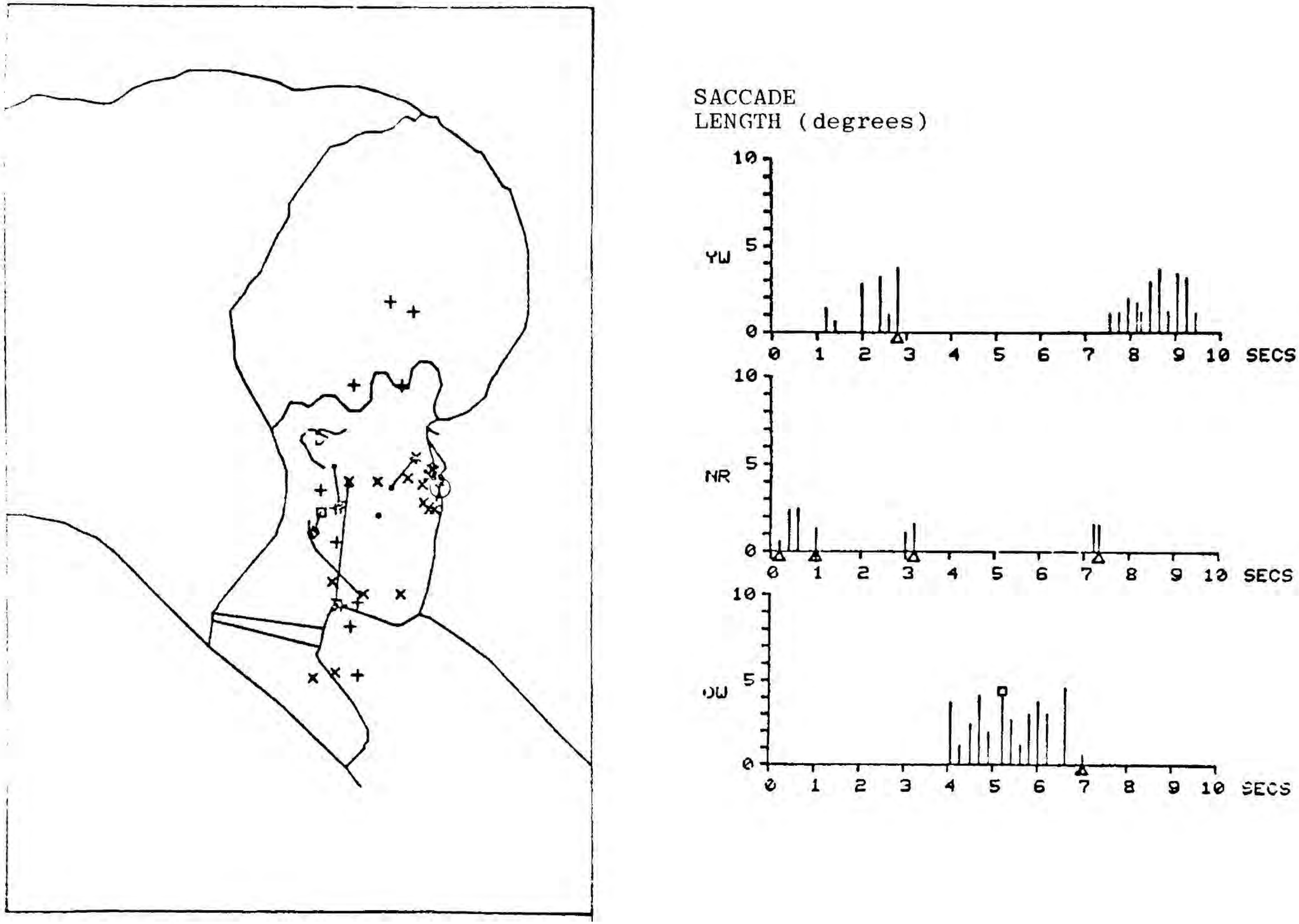
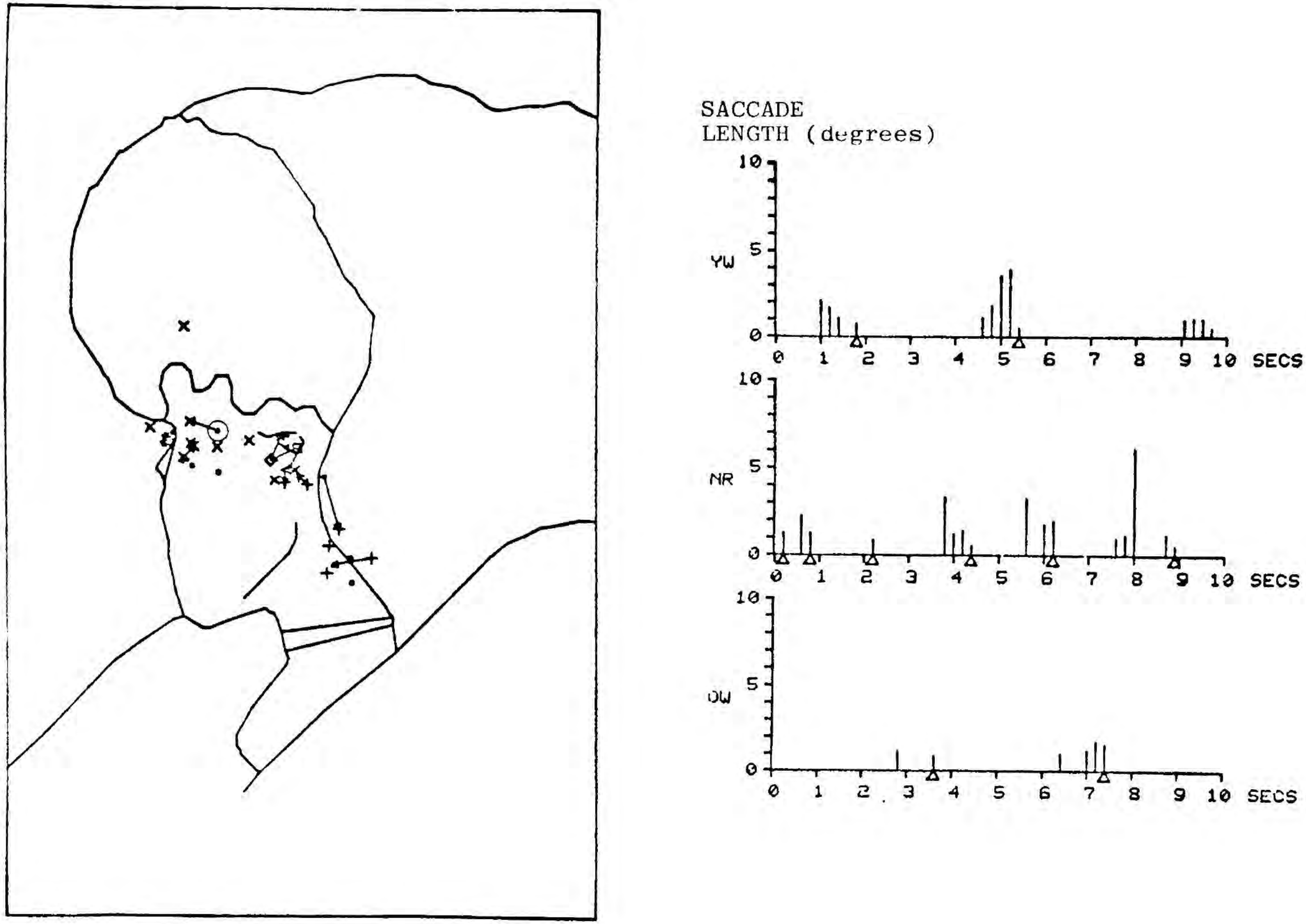


Figure F.1(c) All elements present. Subject EP.



<u>Figure F.1(d)</u> All elements present. Subject PS.

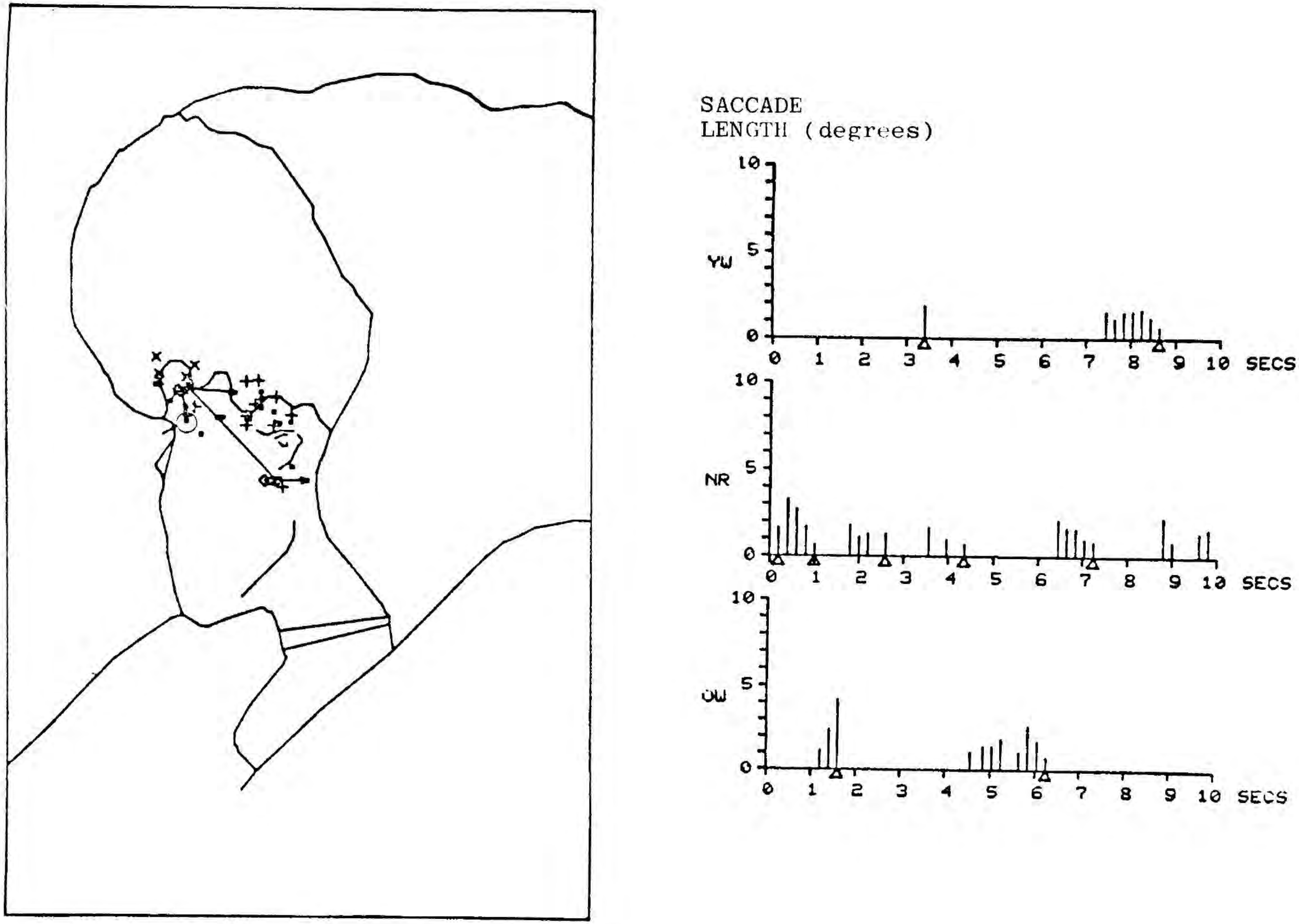


Figure F.1(e) All elements present. Subject LS.

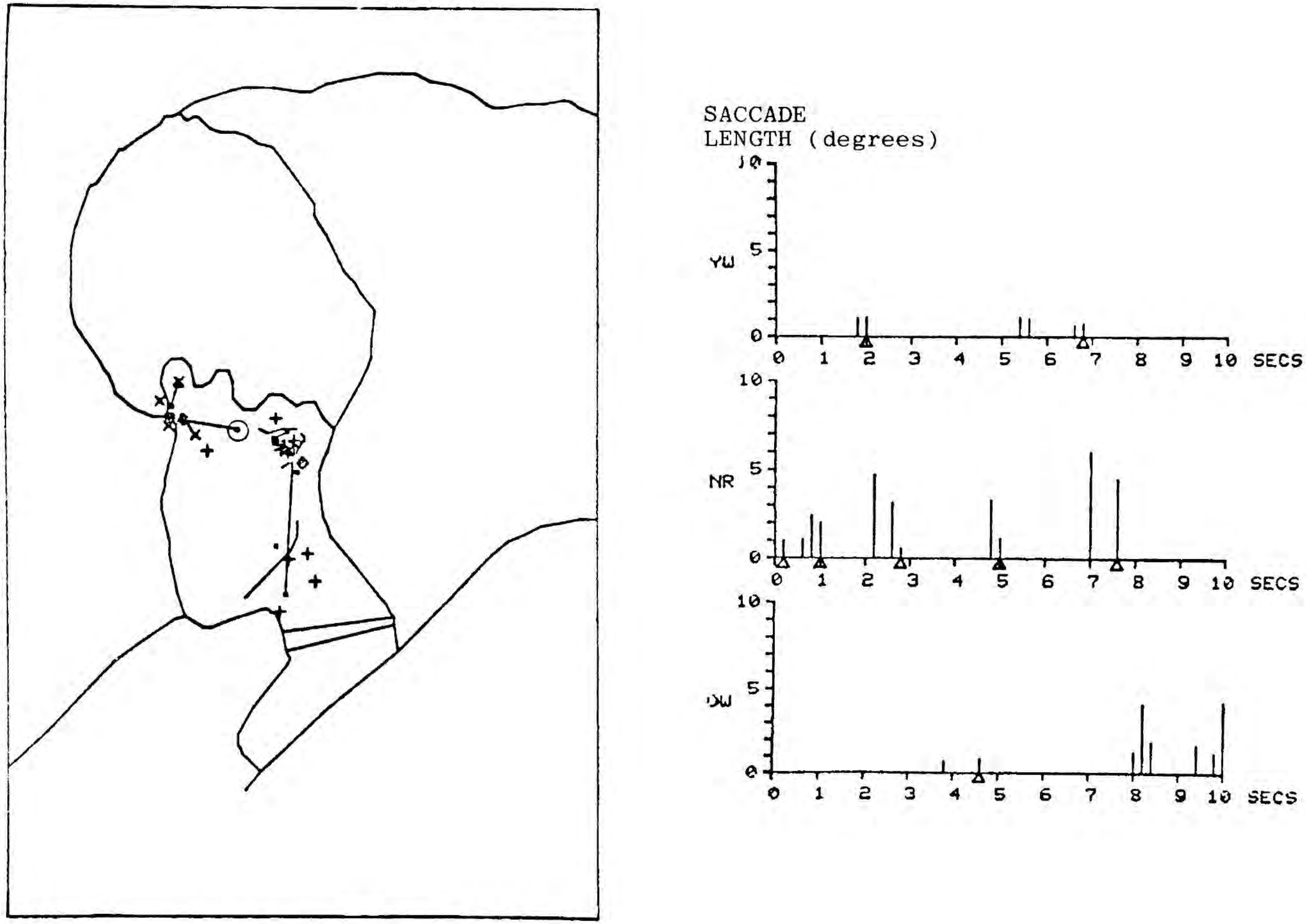


Figure F.2(a) YE element absent. Subject SW.

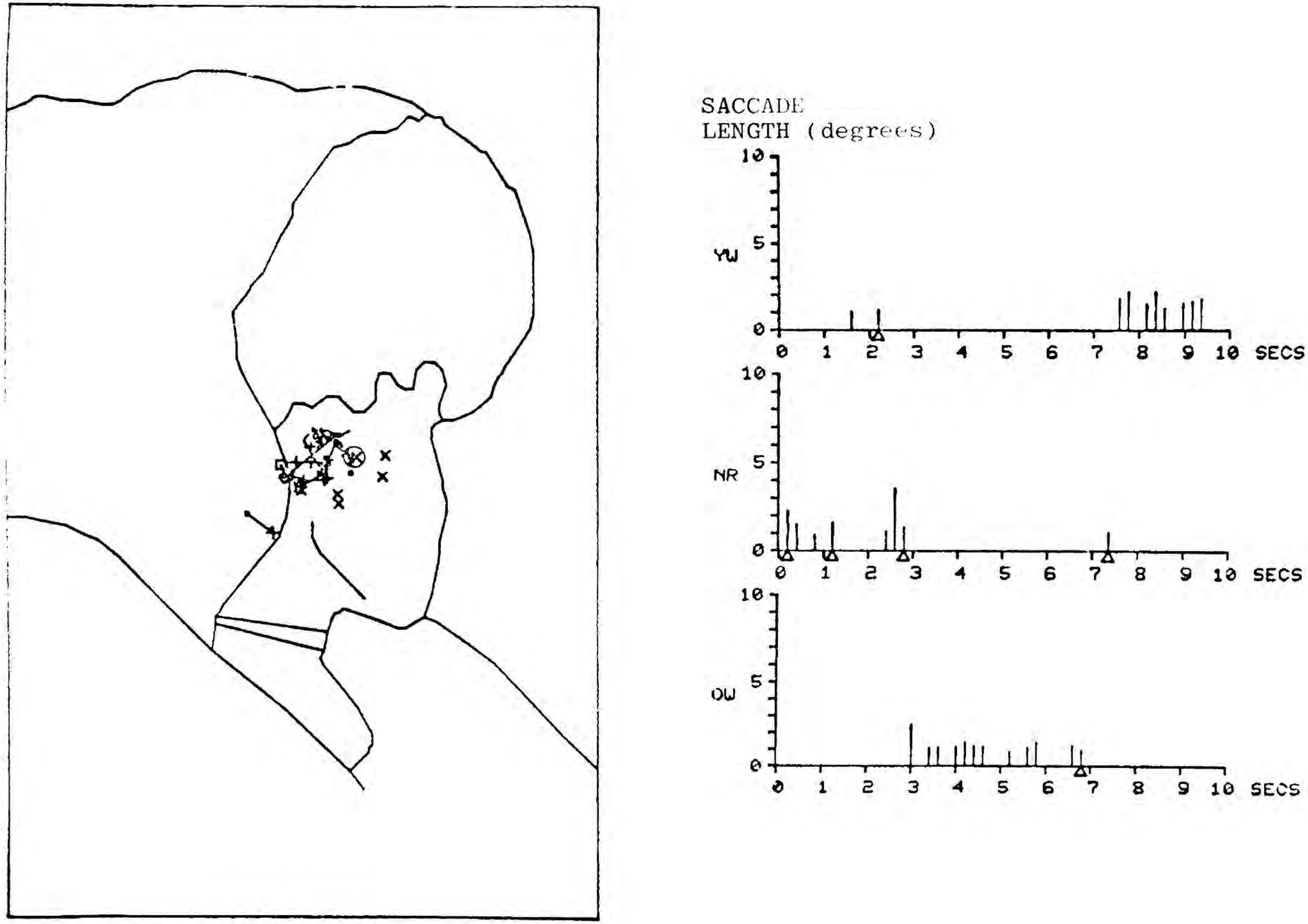
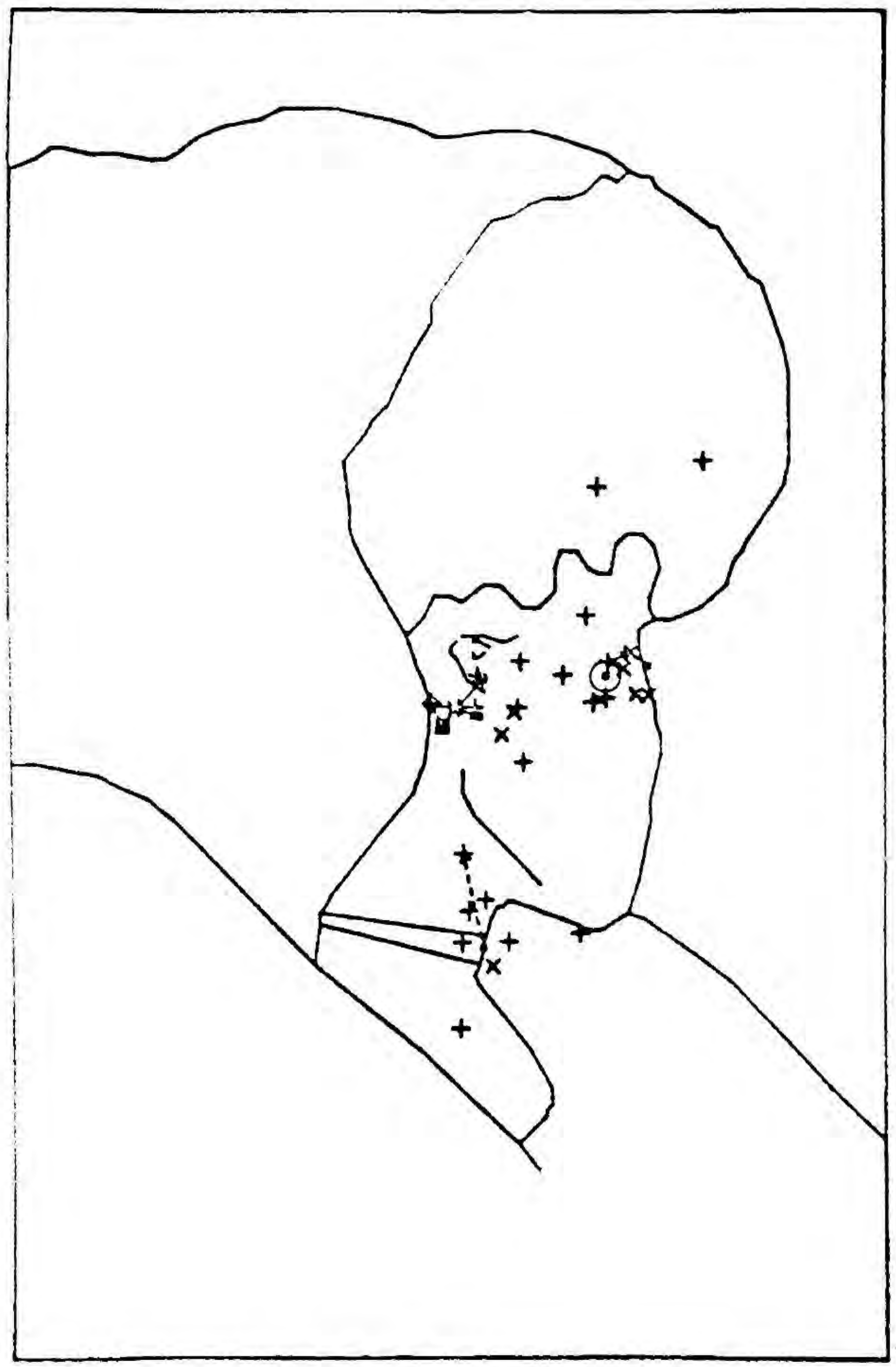
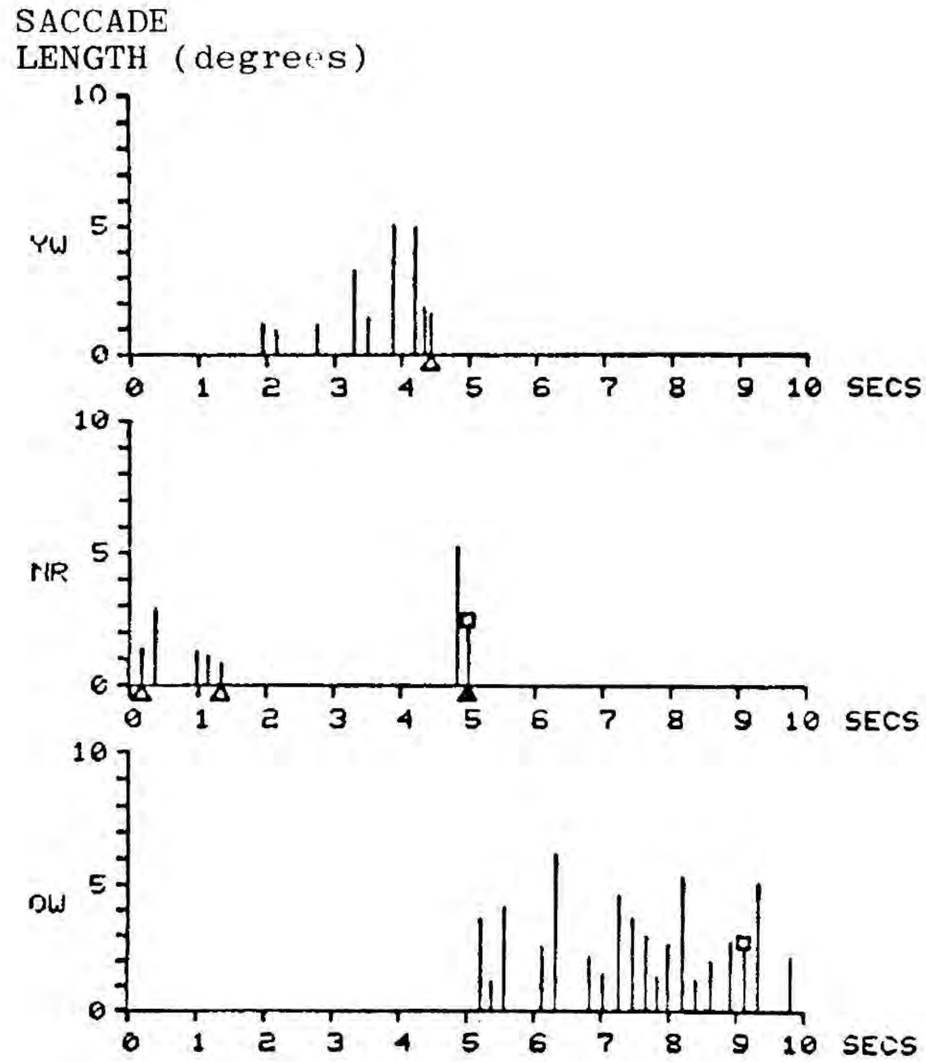
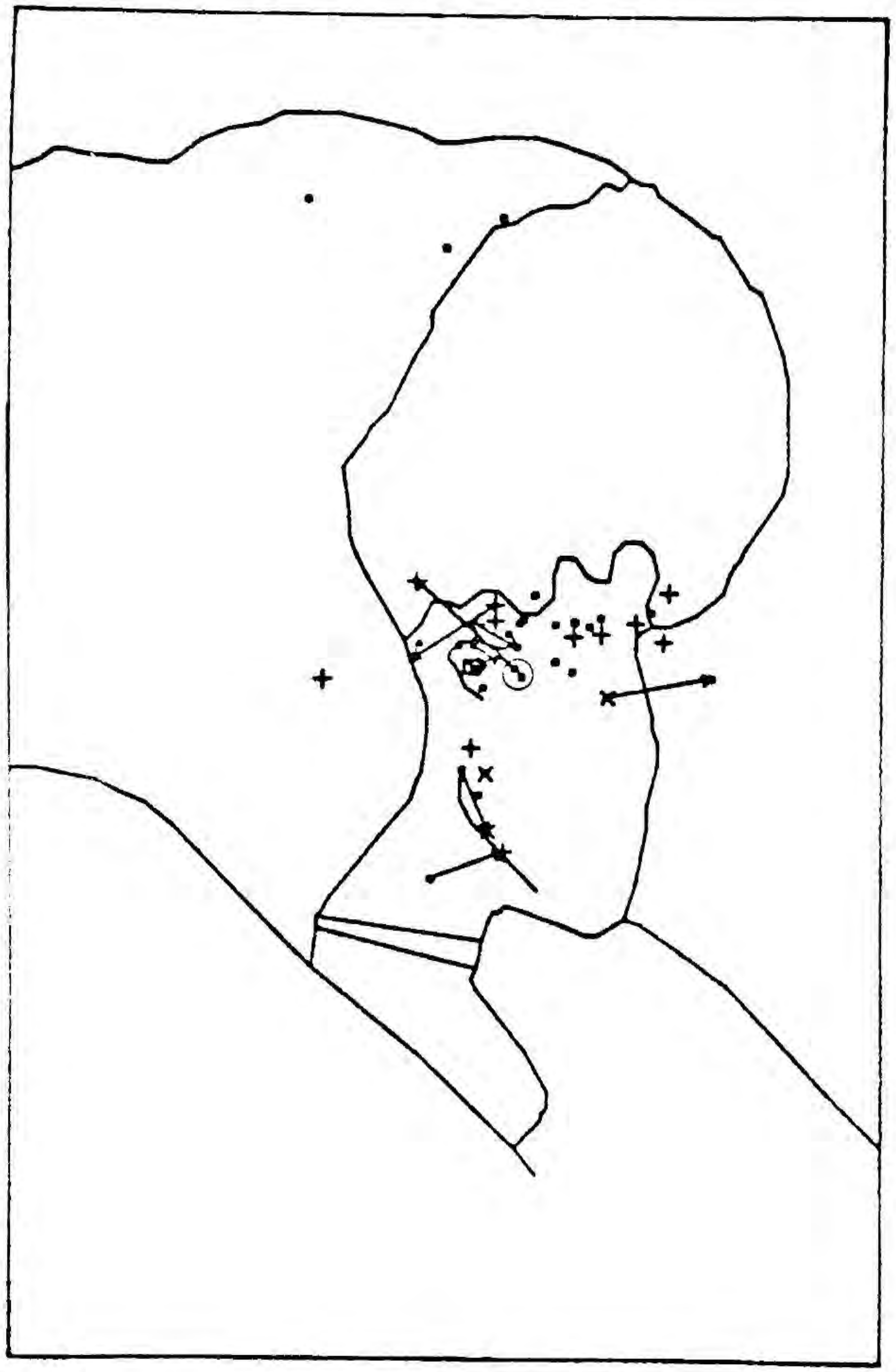


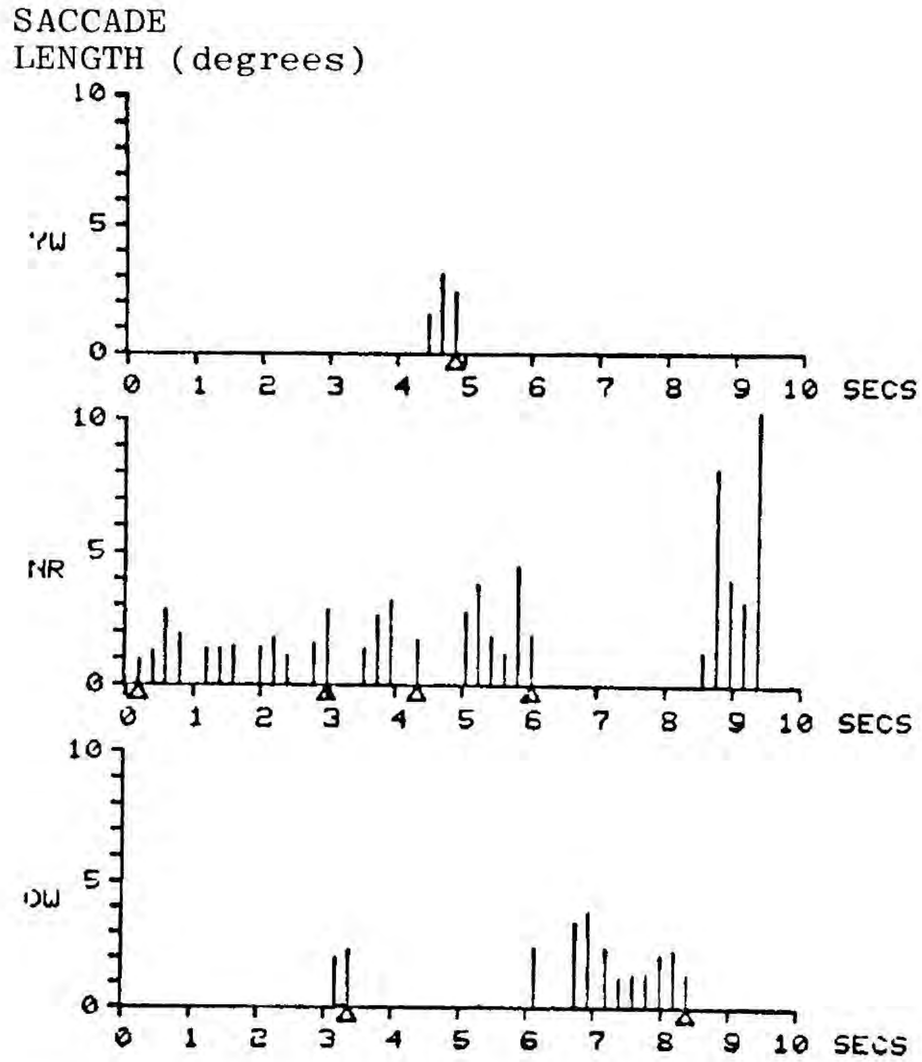
Figure F.2(b) YE element absent. Subject AS.





<u>Figure F.2(c)</u> YE element absent. Subject EP.





<u>Figure F.2(d)</u> YE element absent. Subject PS.

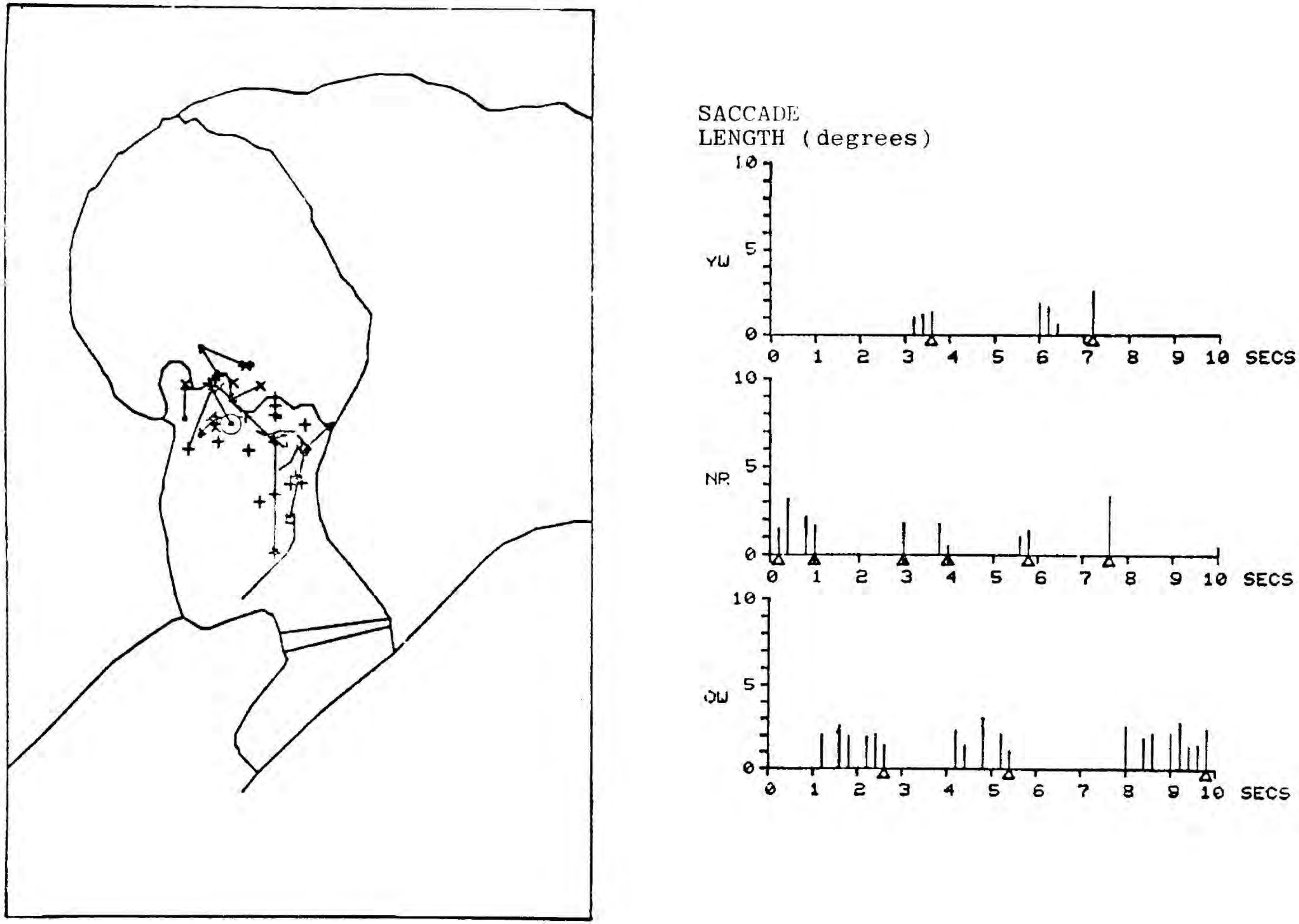


Figure F.2(e) YE element absent. Subject LS.

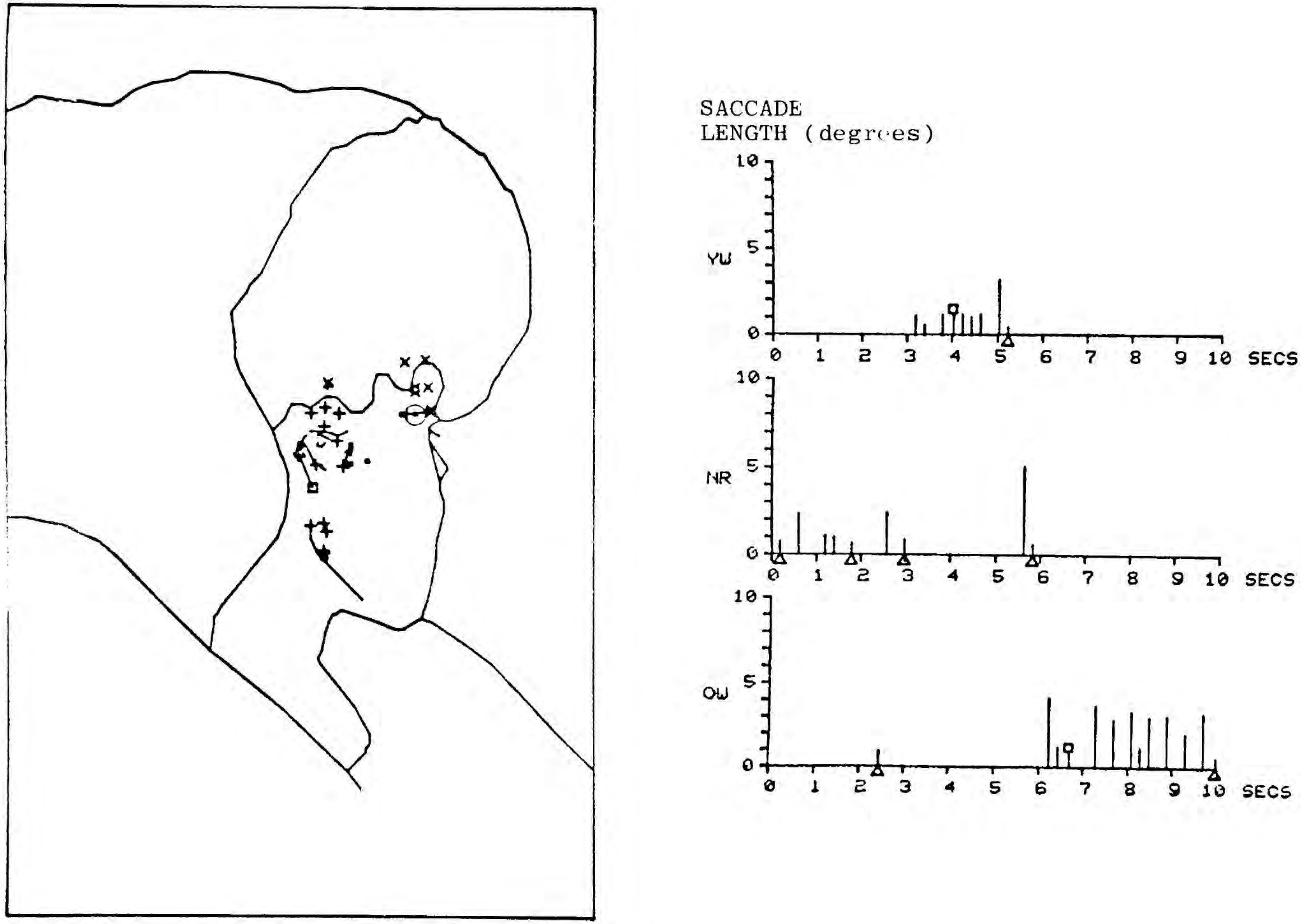
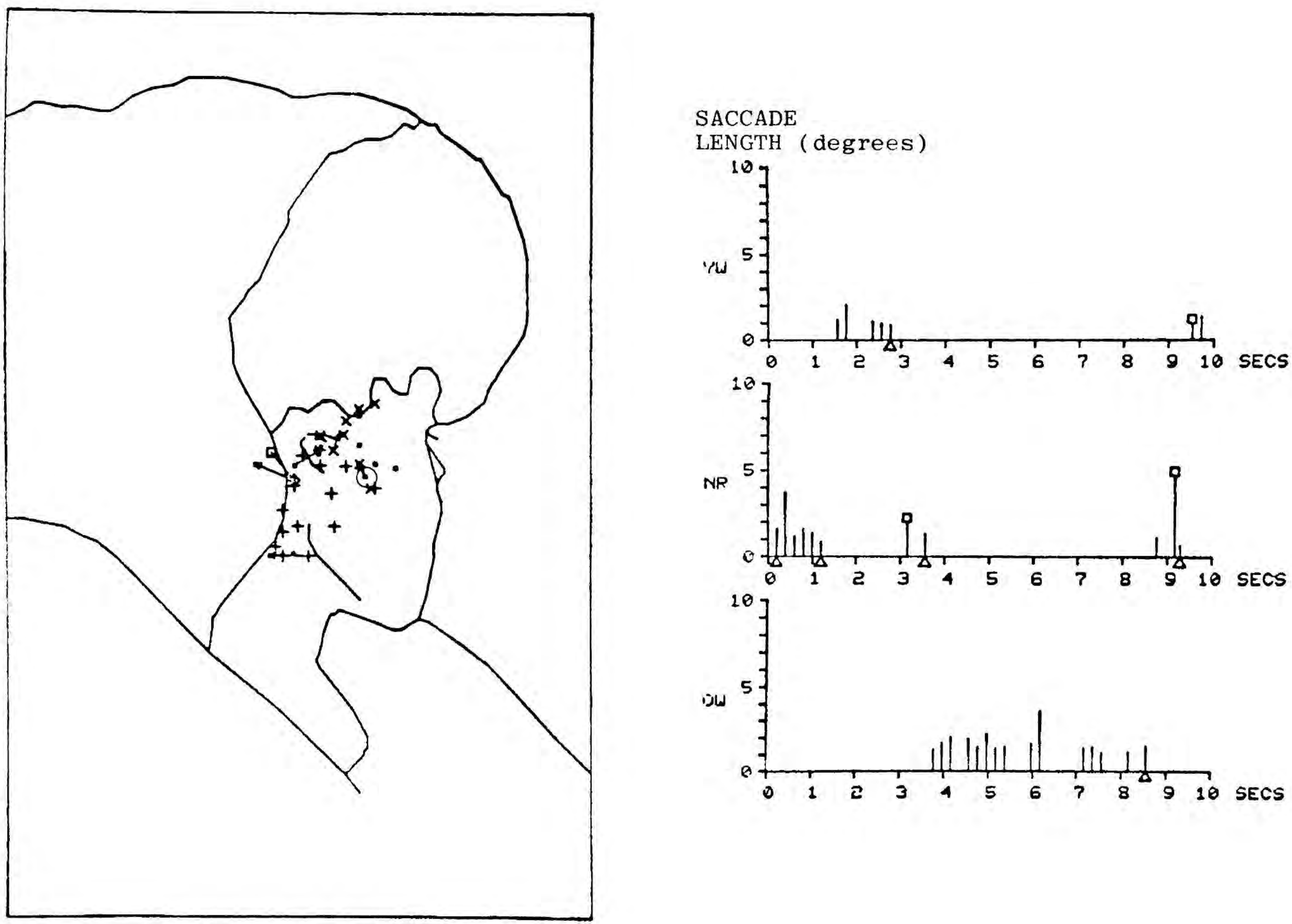


Figure F.3(a) M element absent. Subject SW.



<u>Figure F.3(b)</u> M element absent. Subject AS.

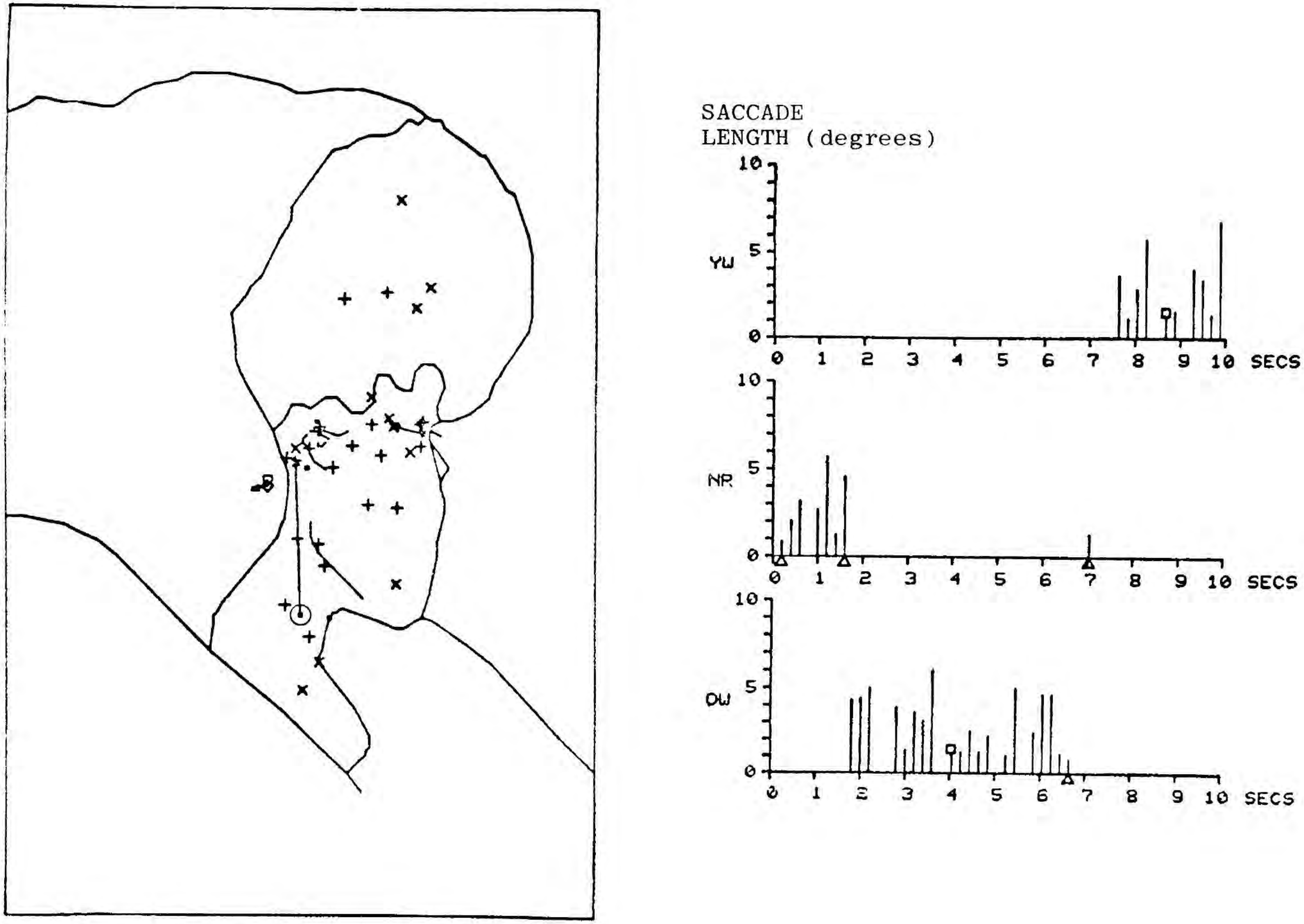


Figure F.3(c) M element absent. Subject EP.

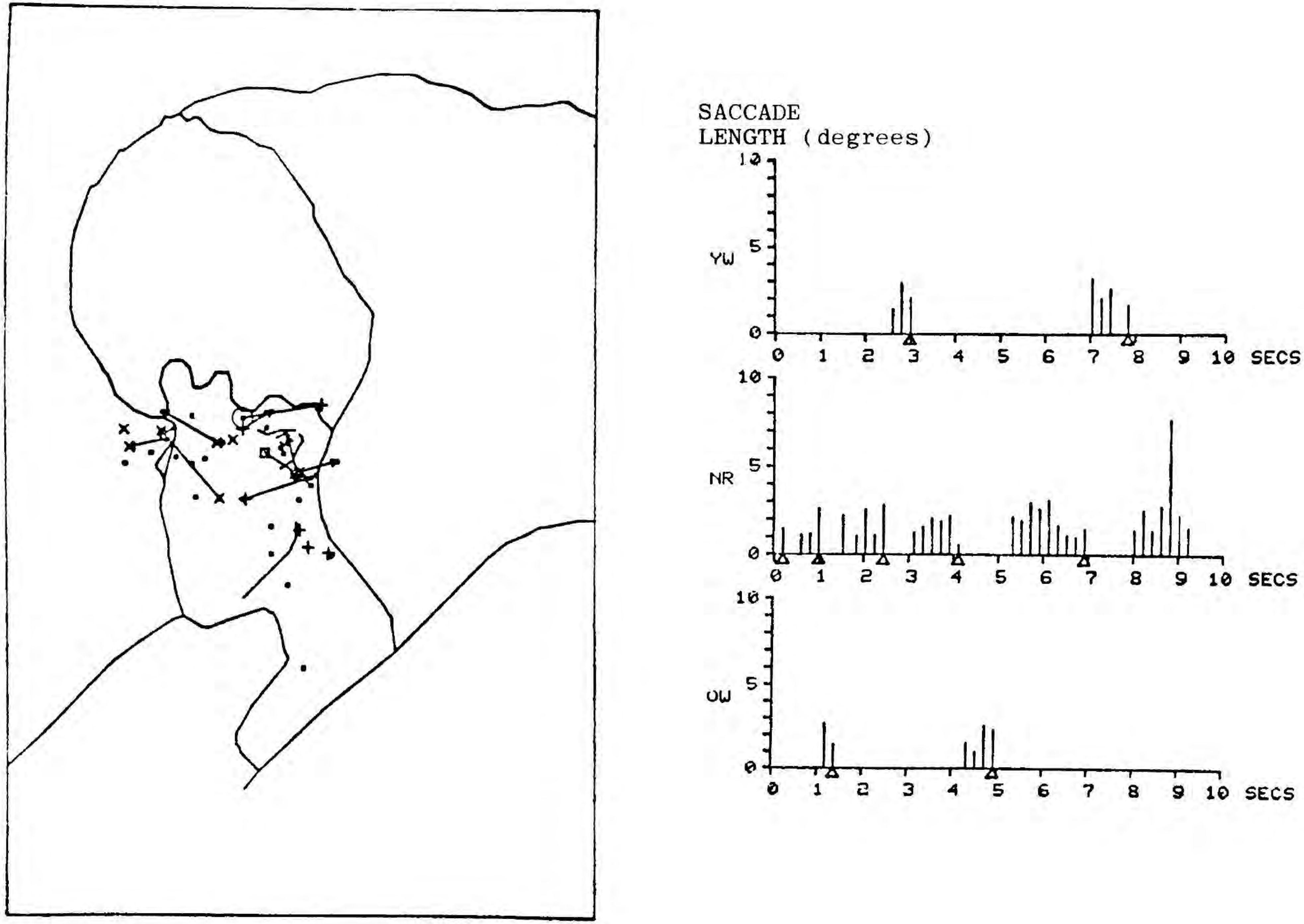


Figure F.3(d) M element absent. Subject PS.

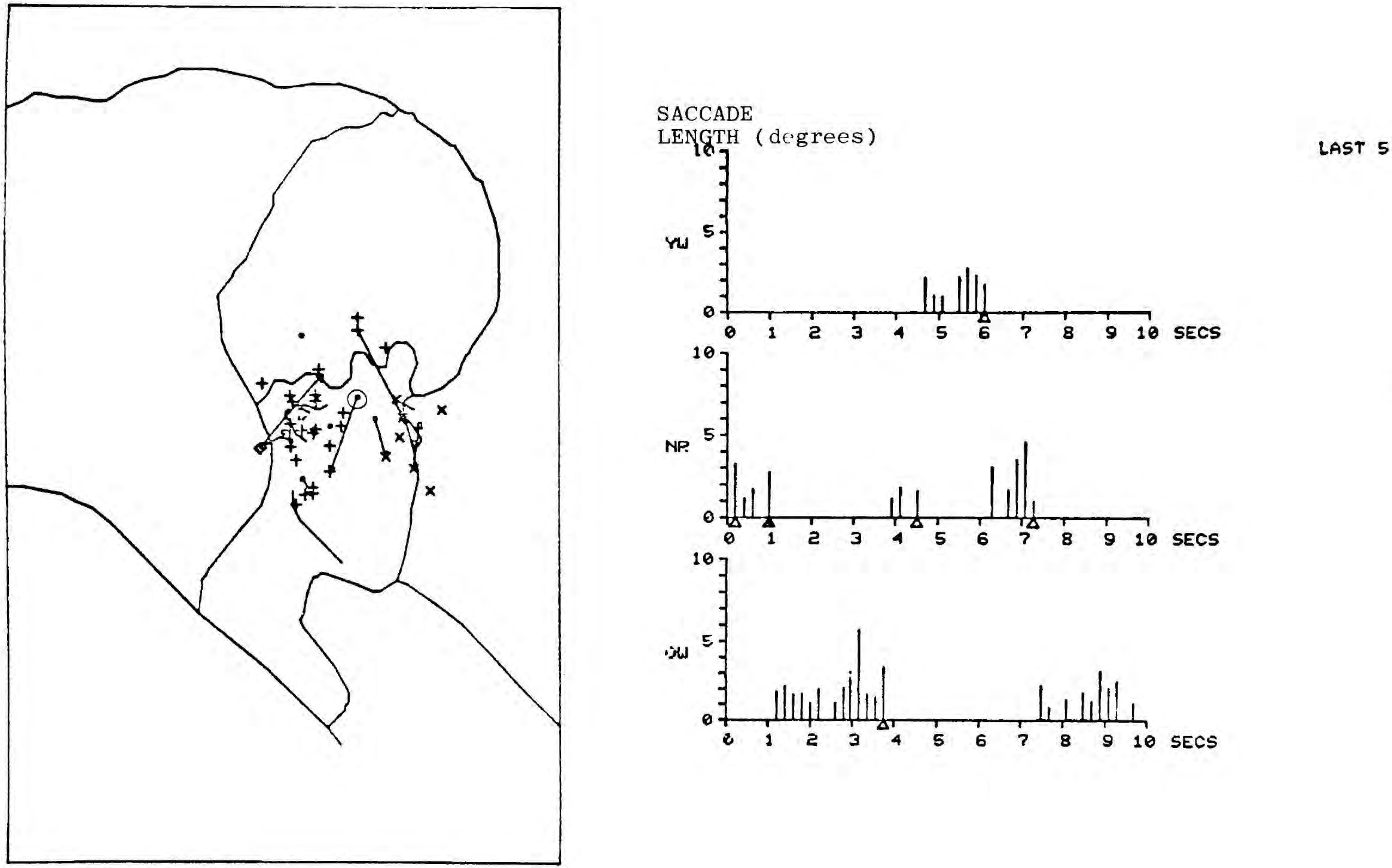
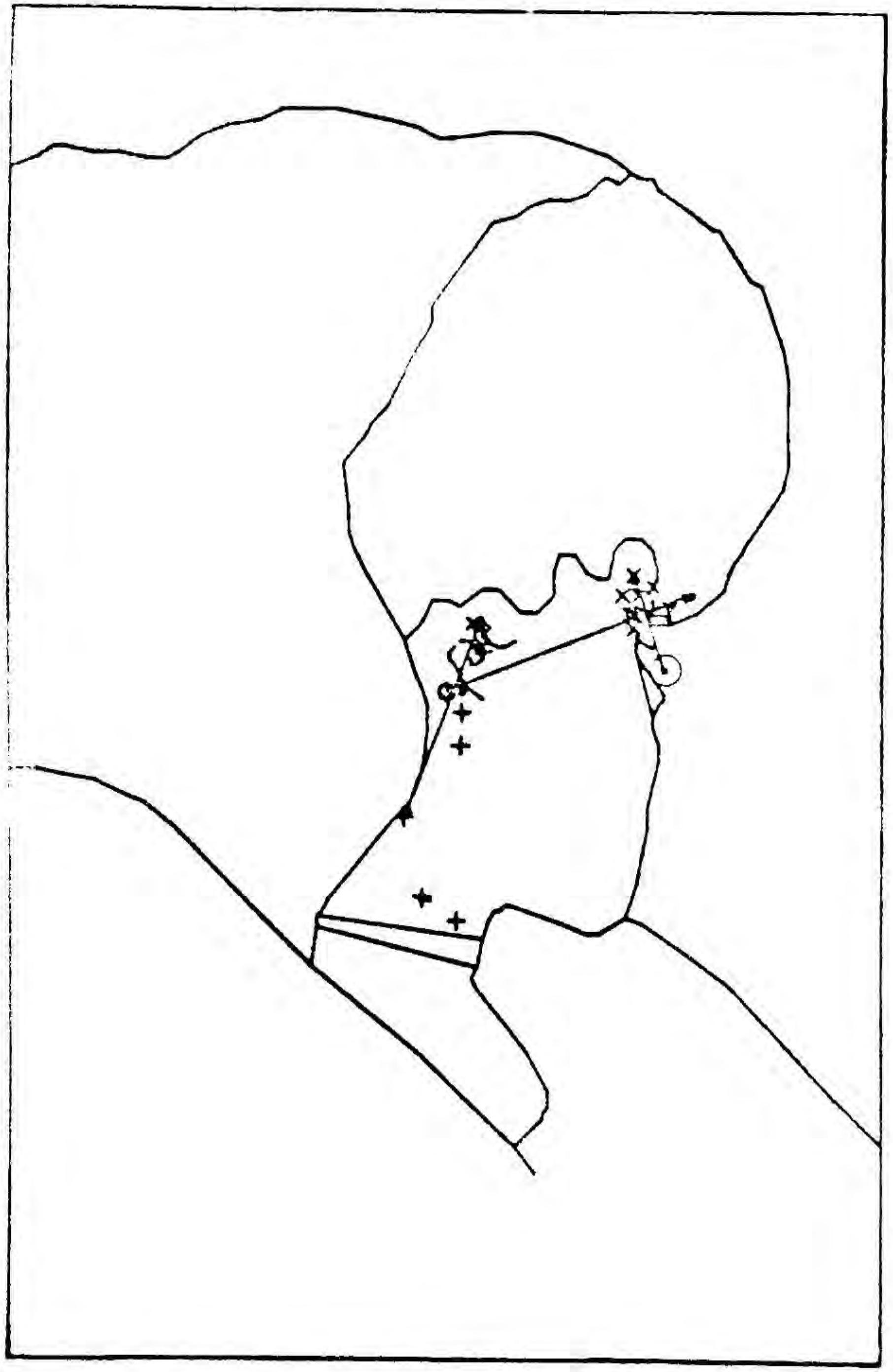


Figure F.3(e) M element absent. Subject LS.



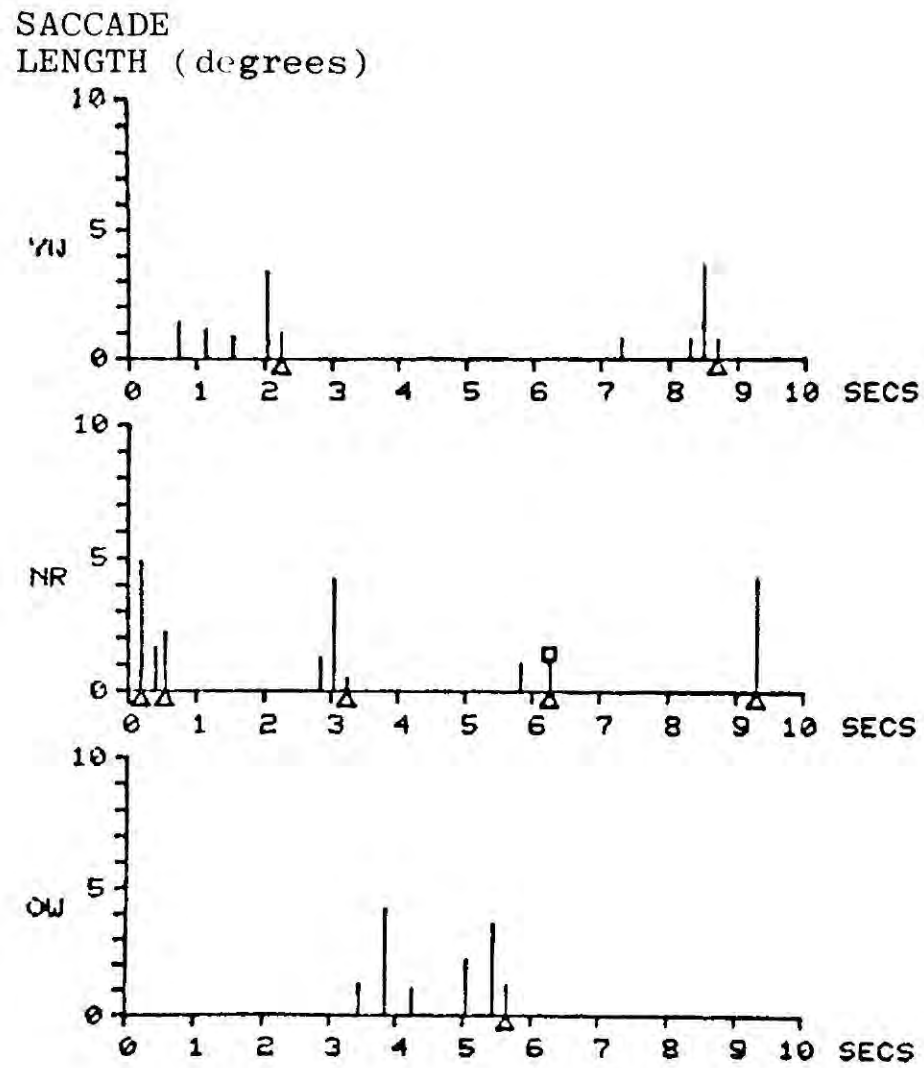


Figure F.4(a) CL element absent. Subject SW.

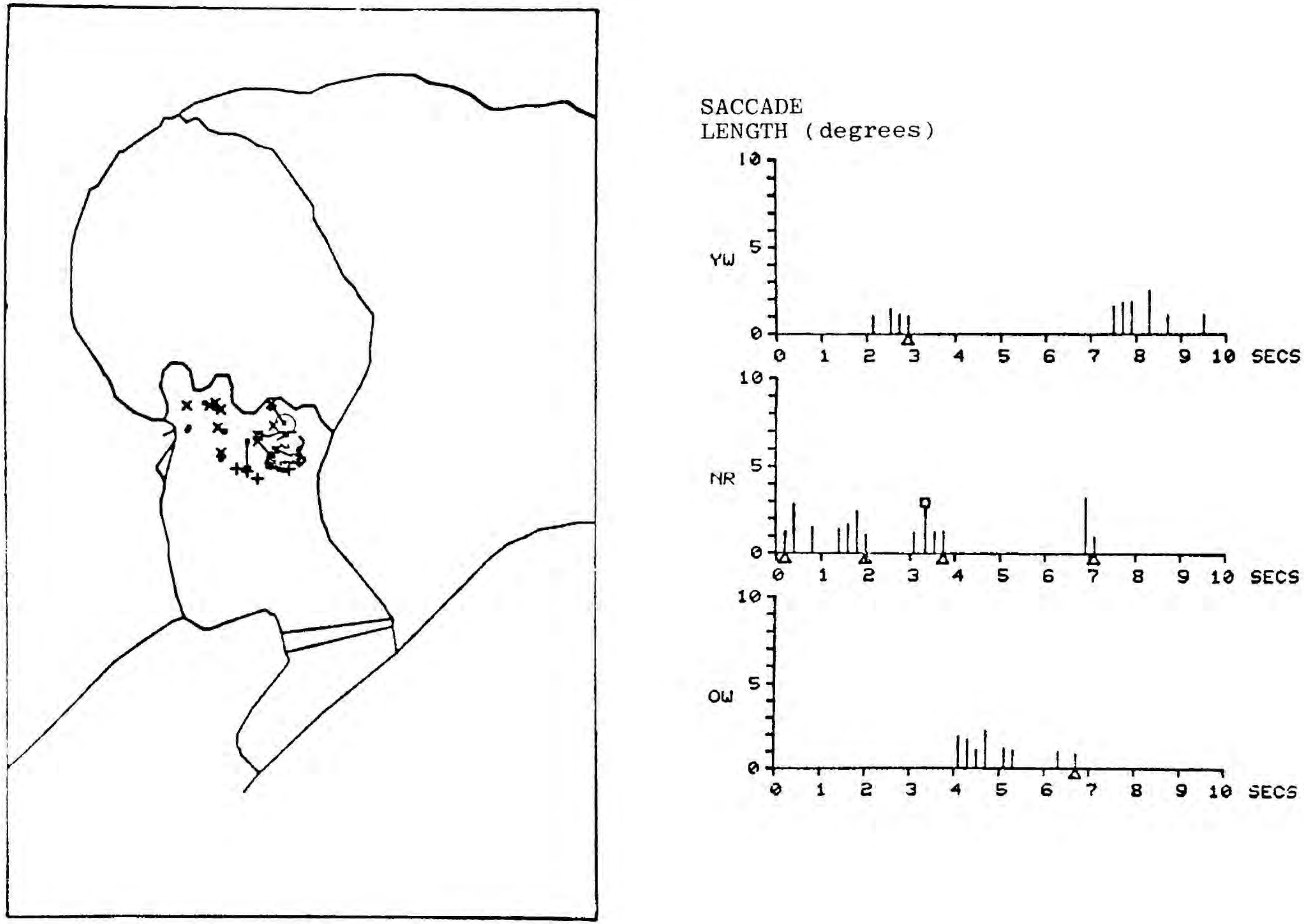
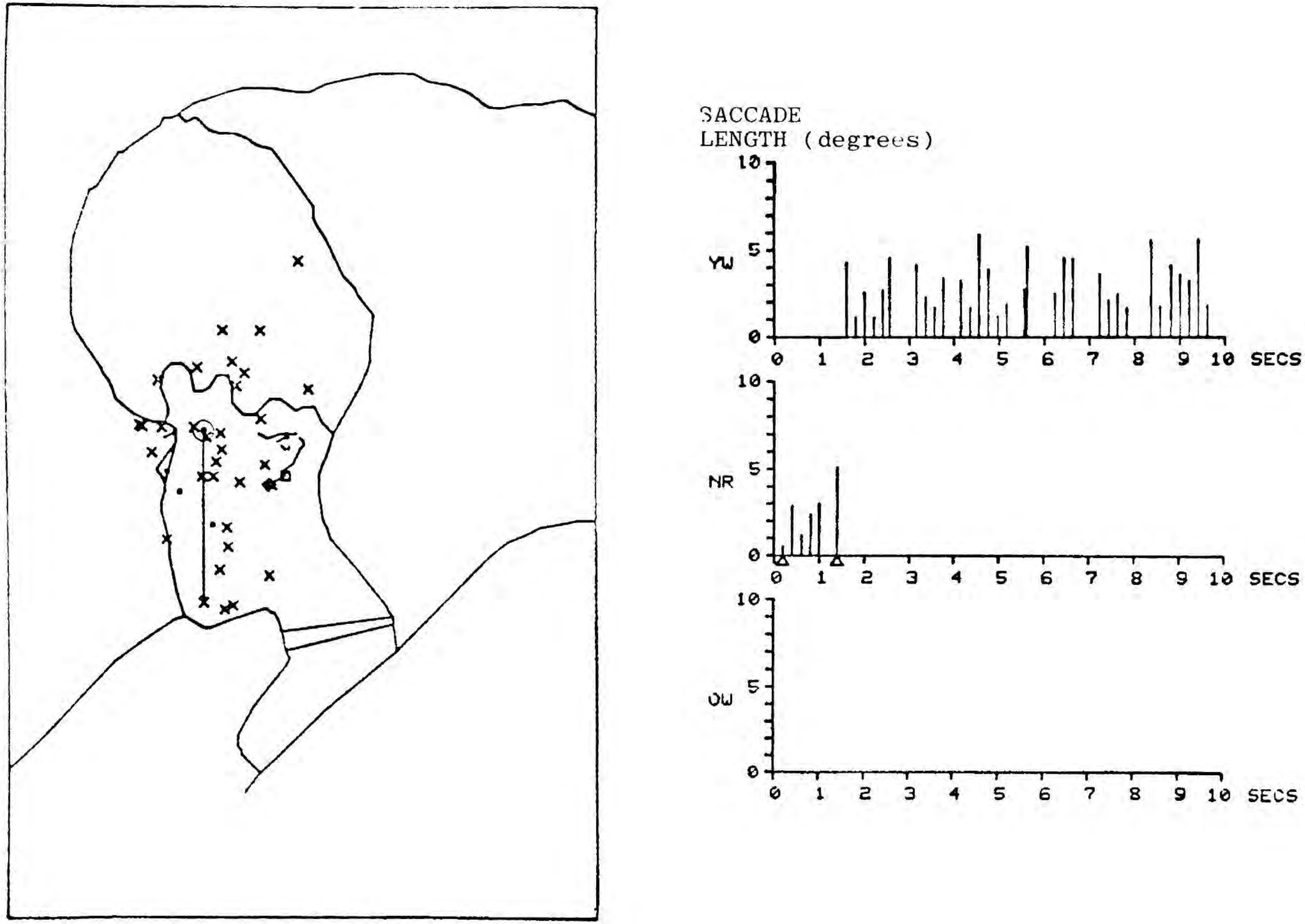


Figure F.4(b) CL element absent. Subject AS.



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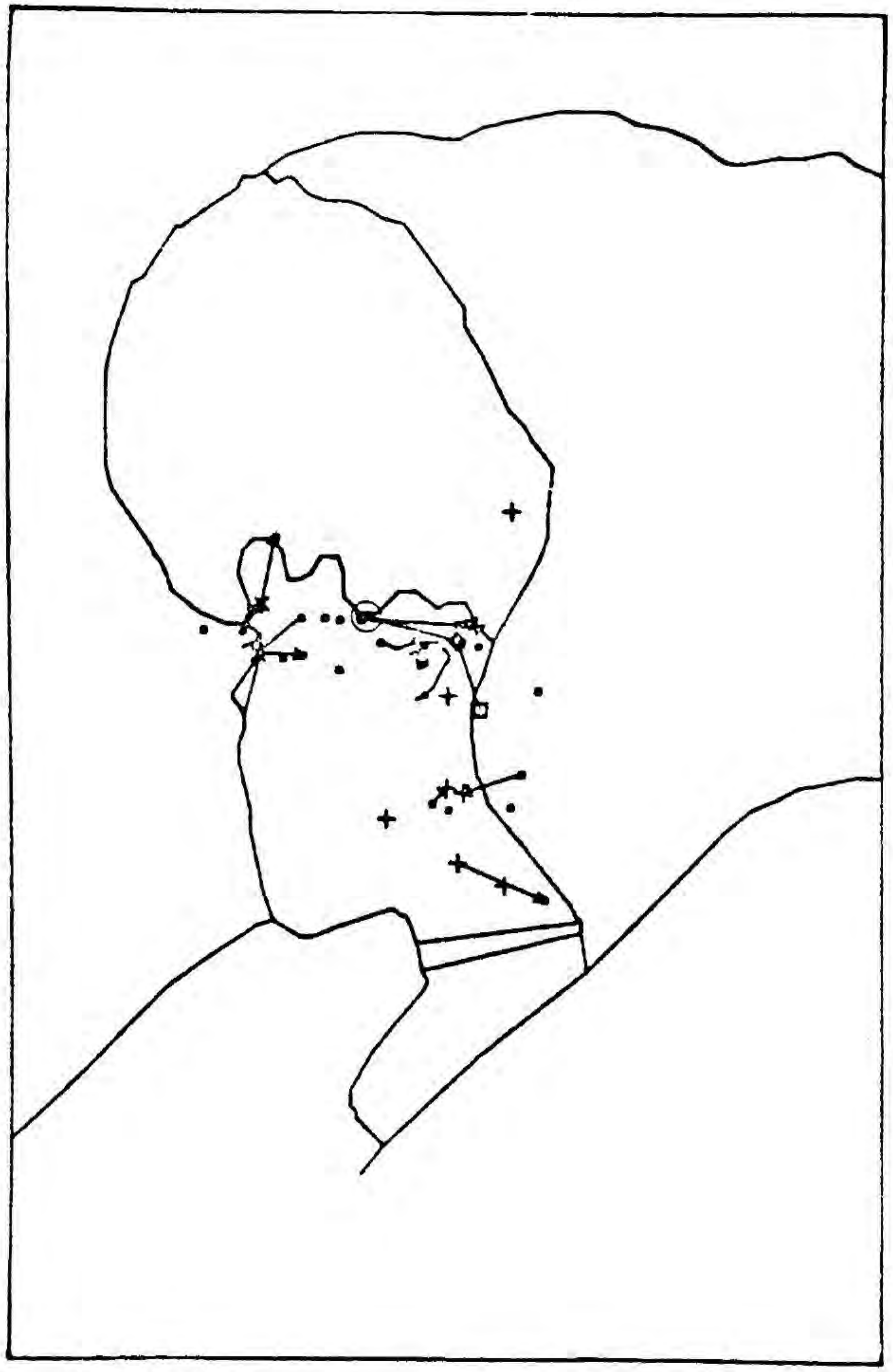

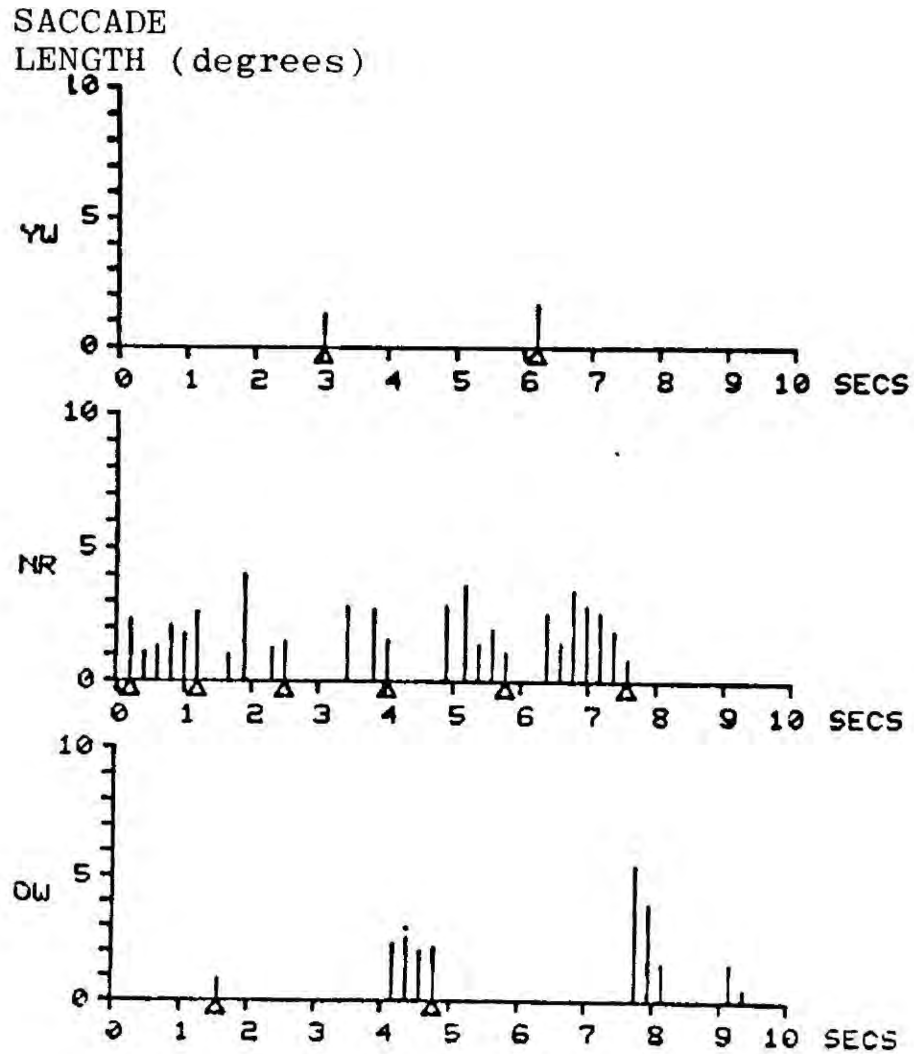

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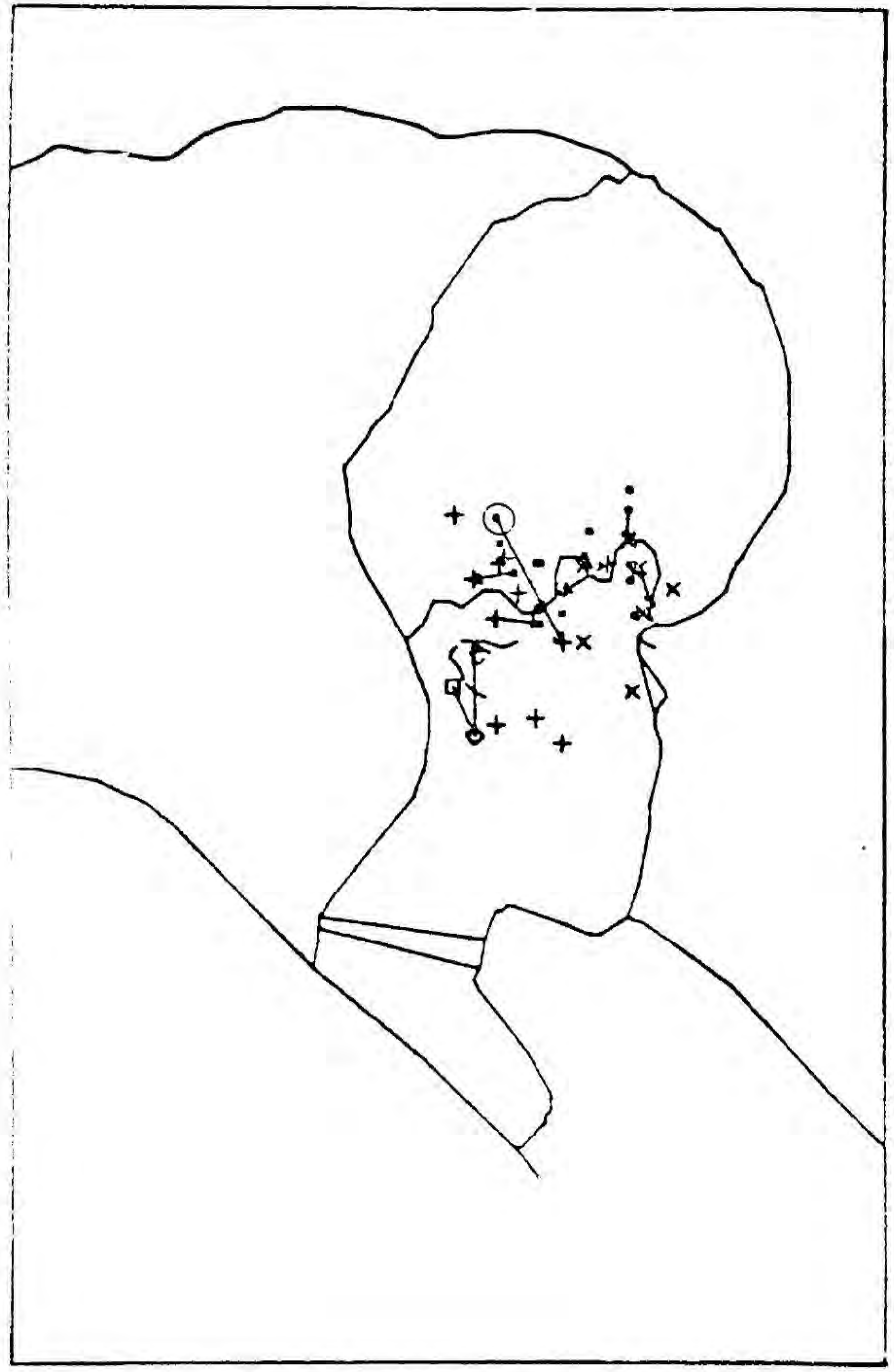
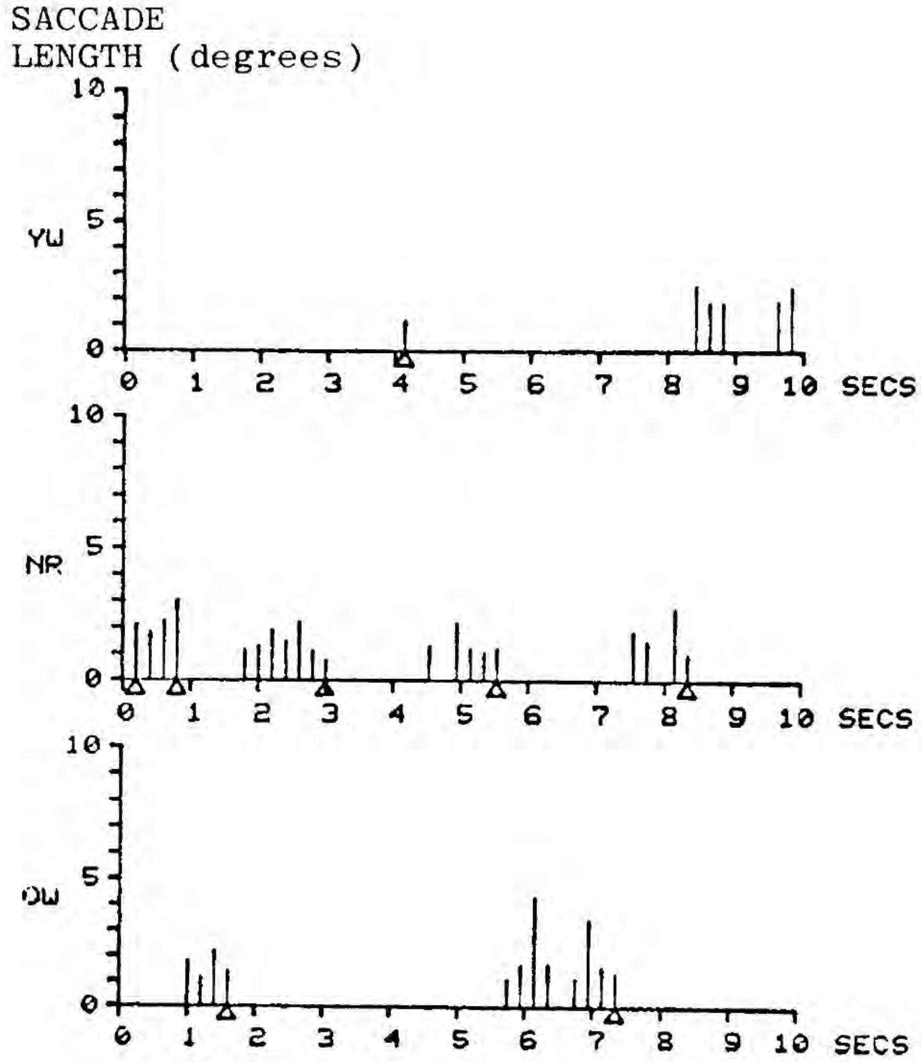
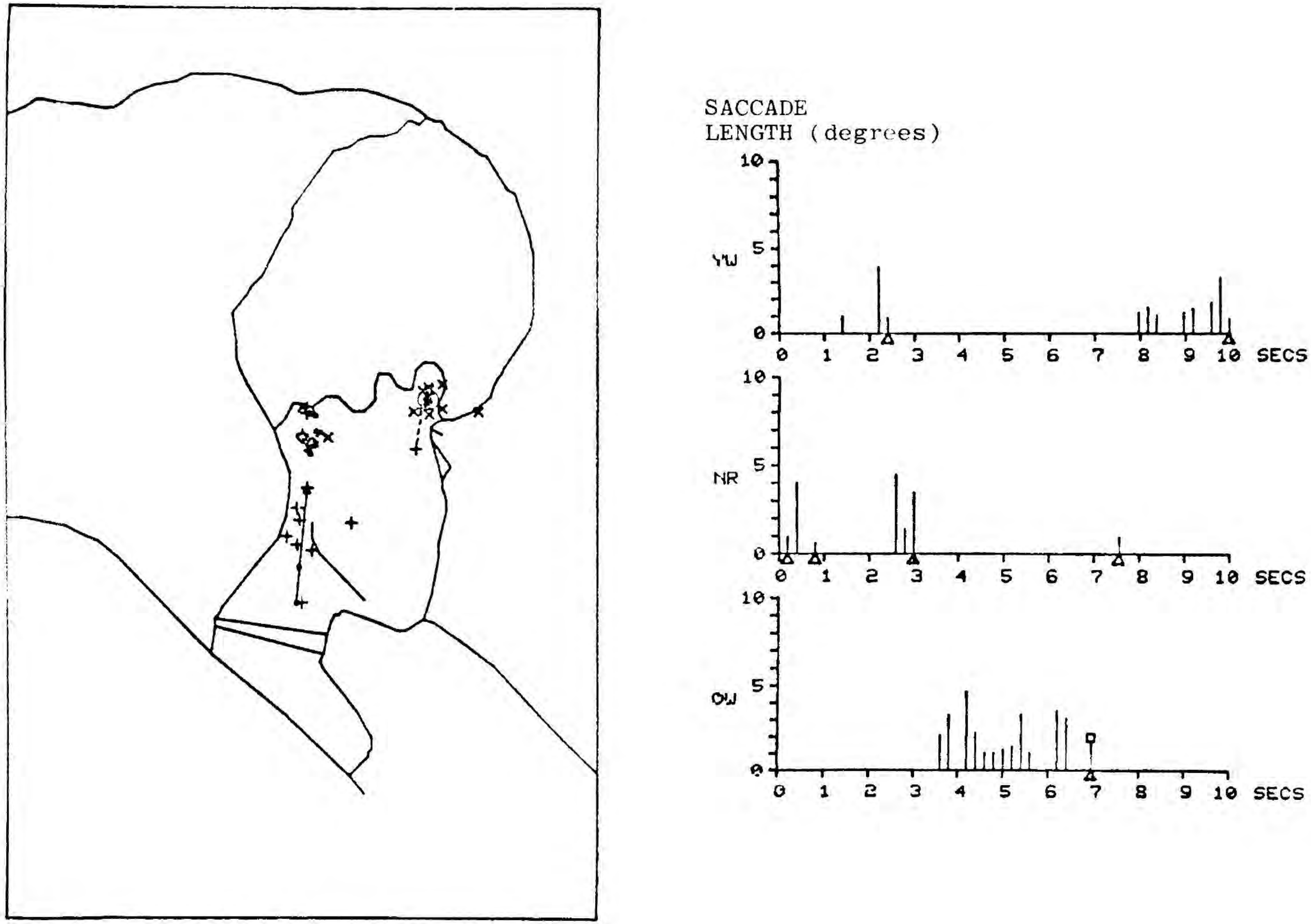
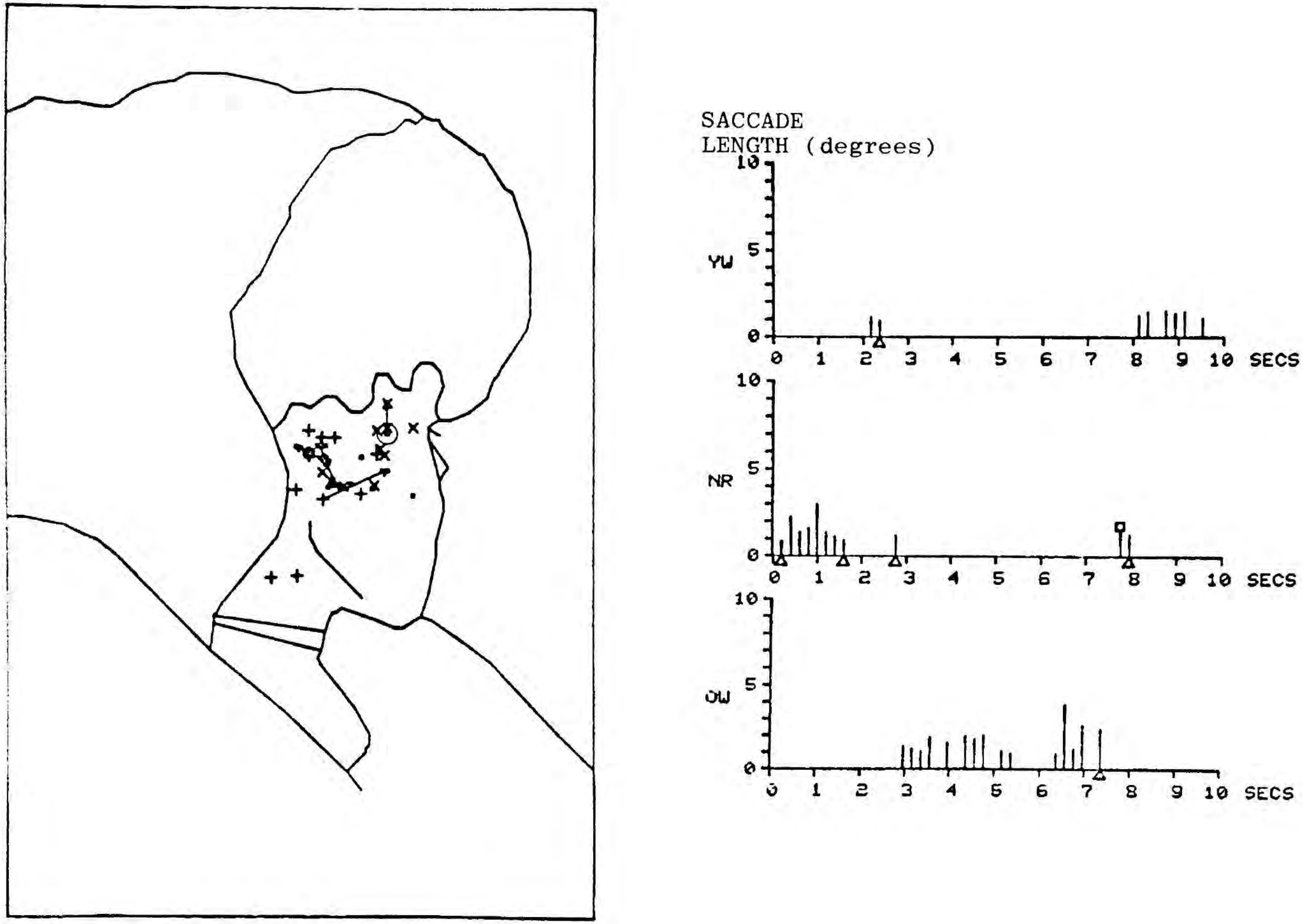




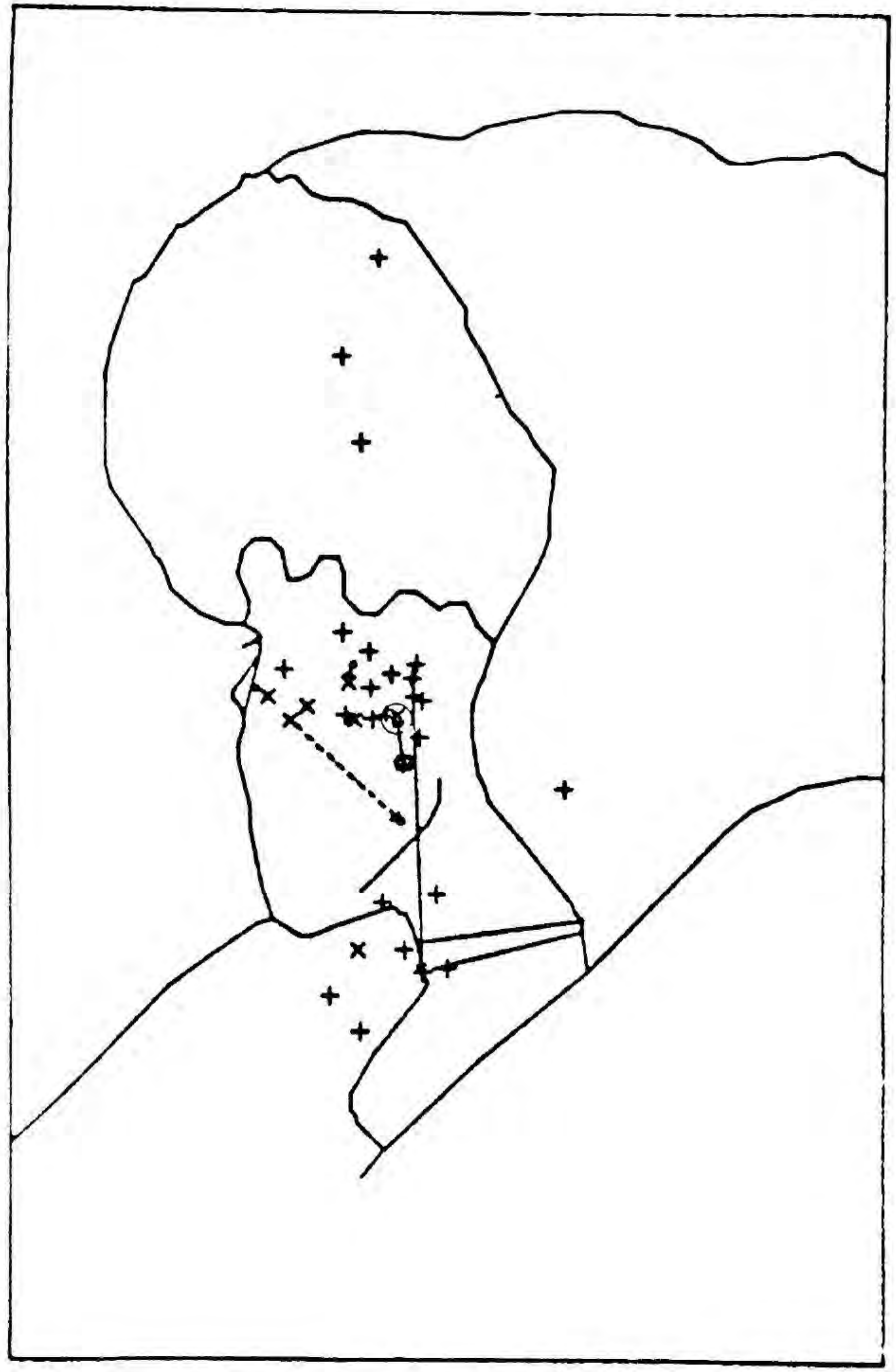
<u>Figure F.4(e)</u> CL element absent. Subject LS.



<u>Figure F.5(a)</u> E/EC element absent. Subject SW.



<u>Figure F.5(b)</u> E/EC element absent. Subject AS.



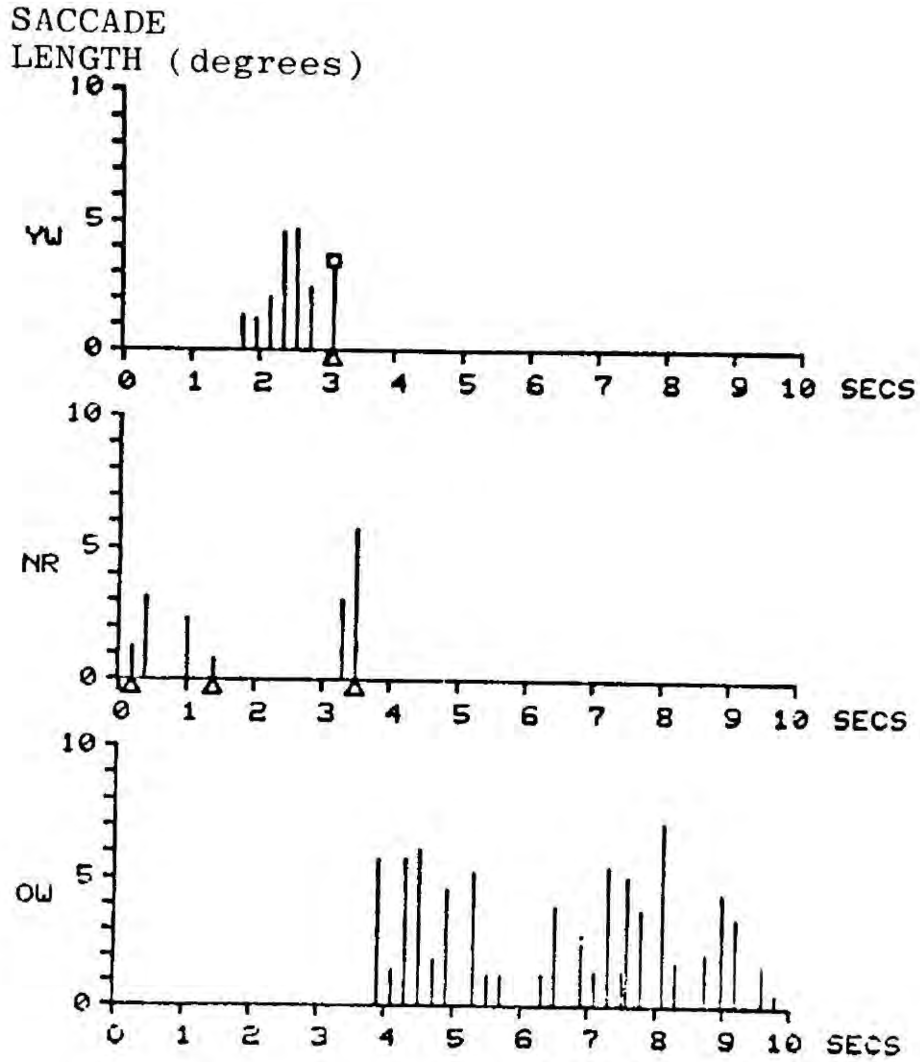
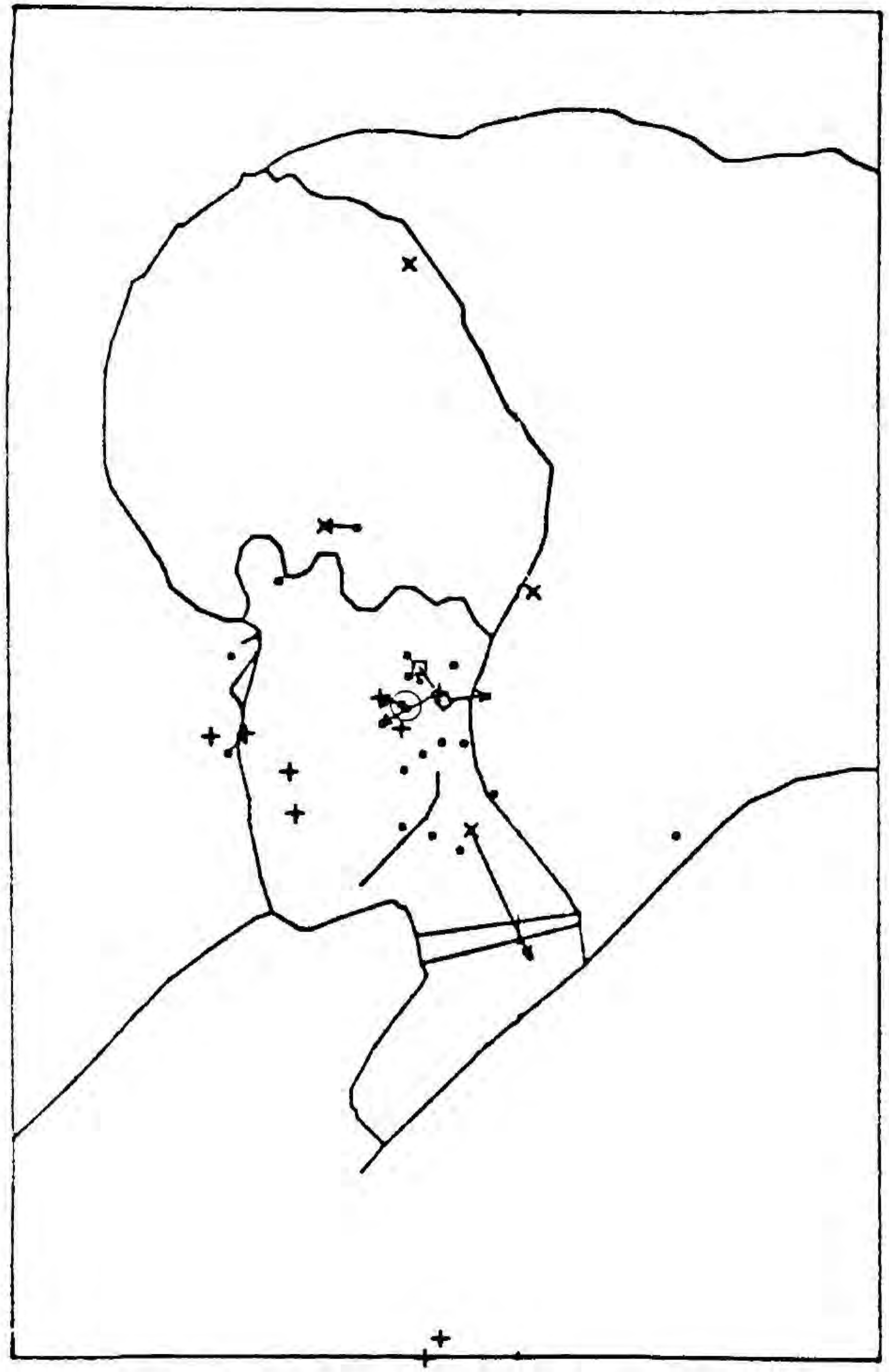


Figure F.5(c) E/EC element absent. Subject EP.



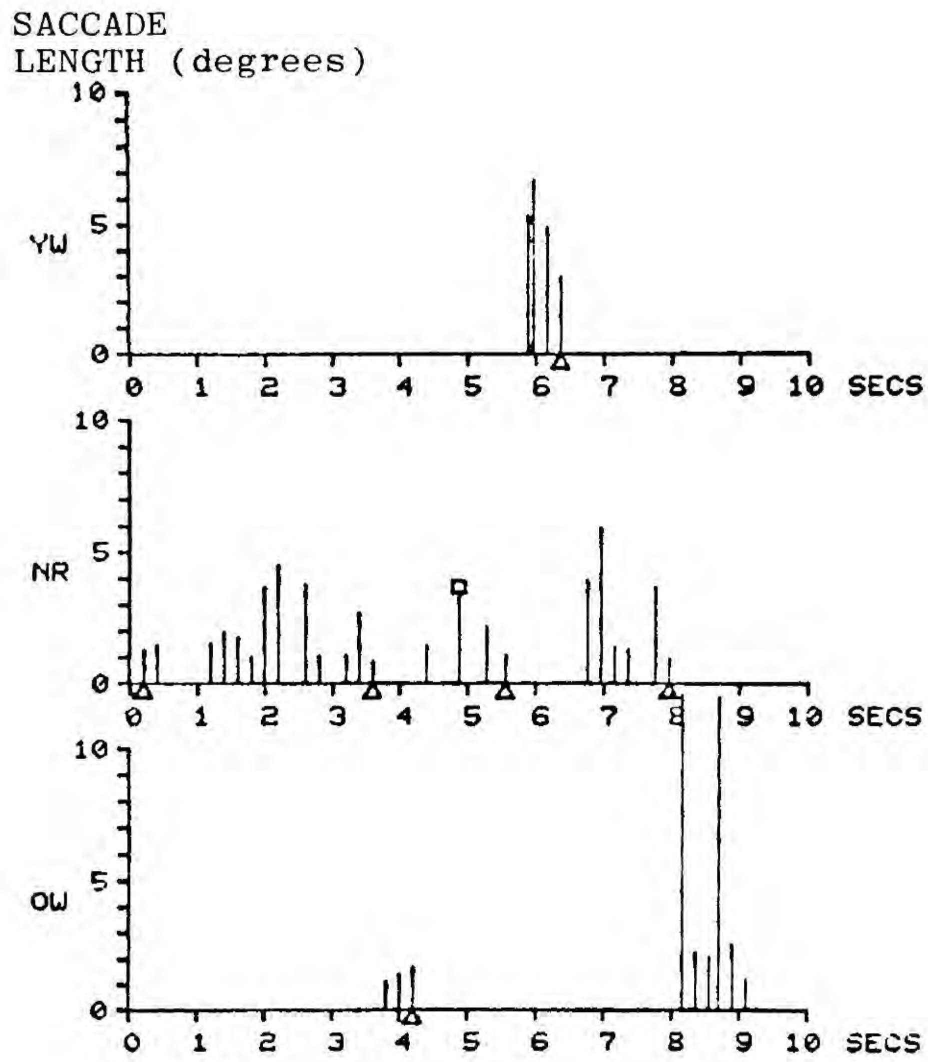


Figure F.5(d) E/EC element absent. Subject PS.

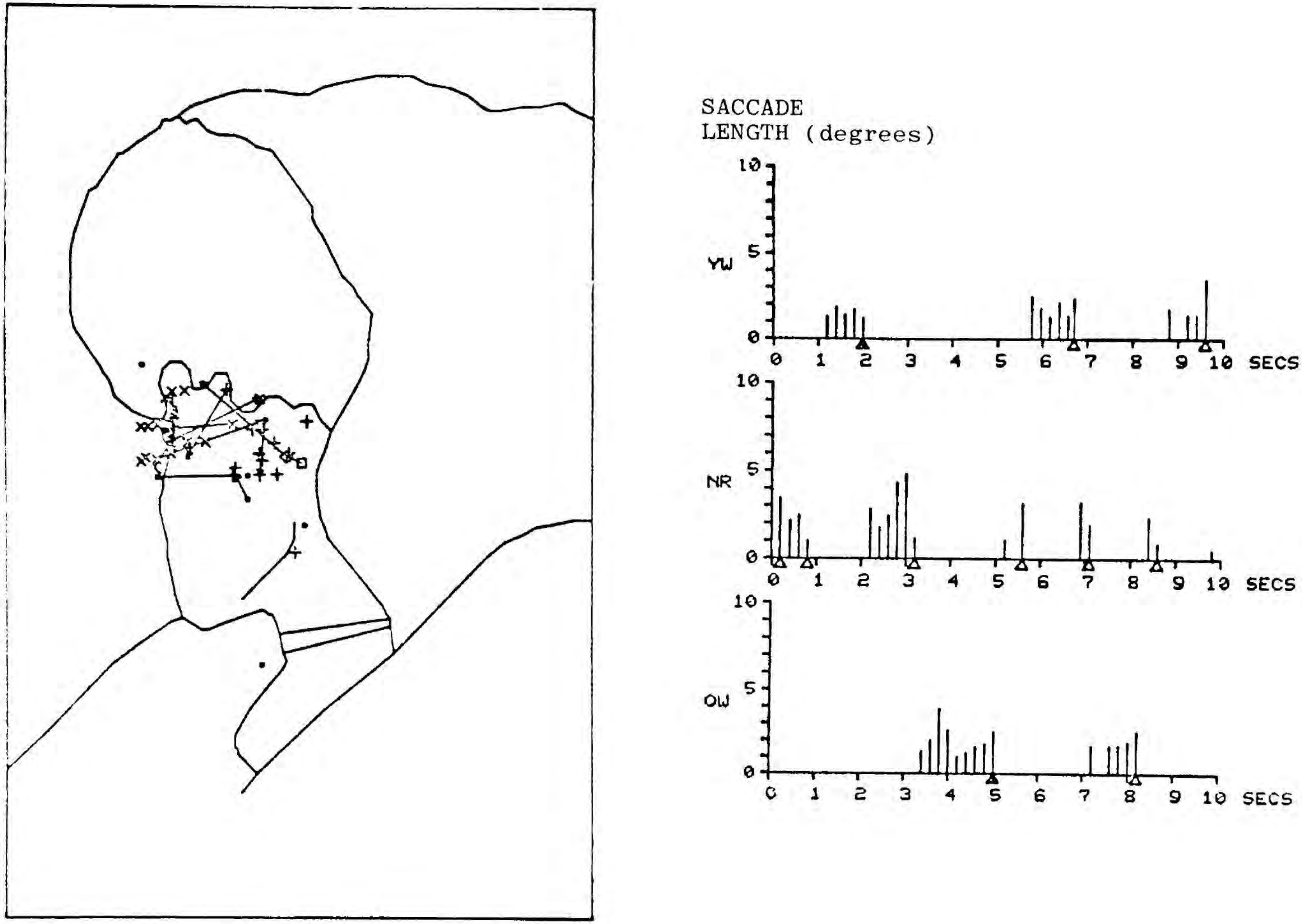


Figure F.5(e) E/EC element absent. Subject LS.

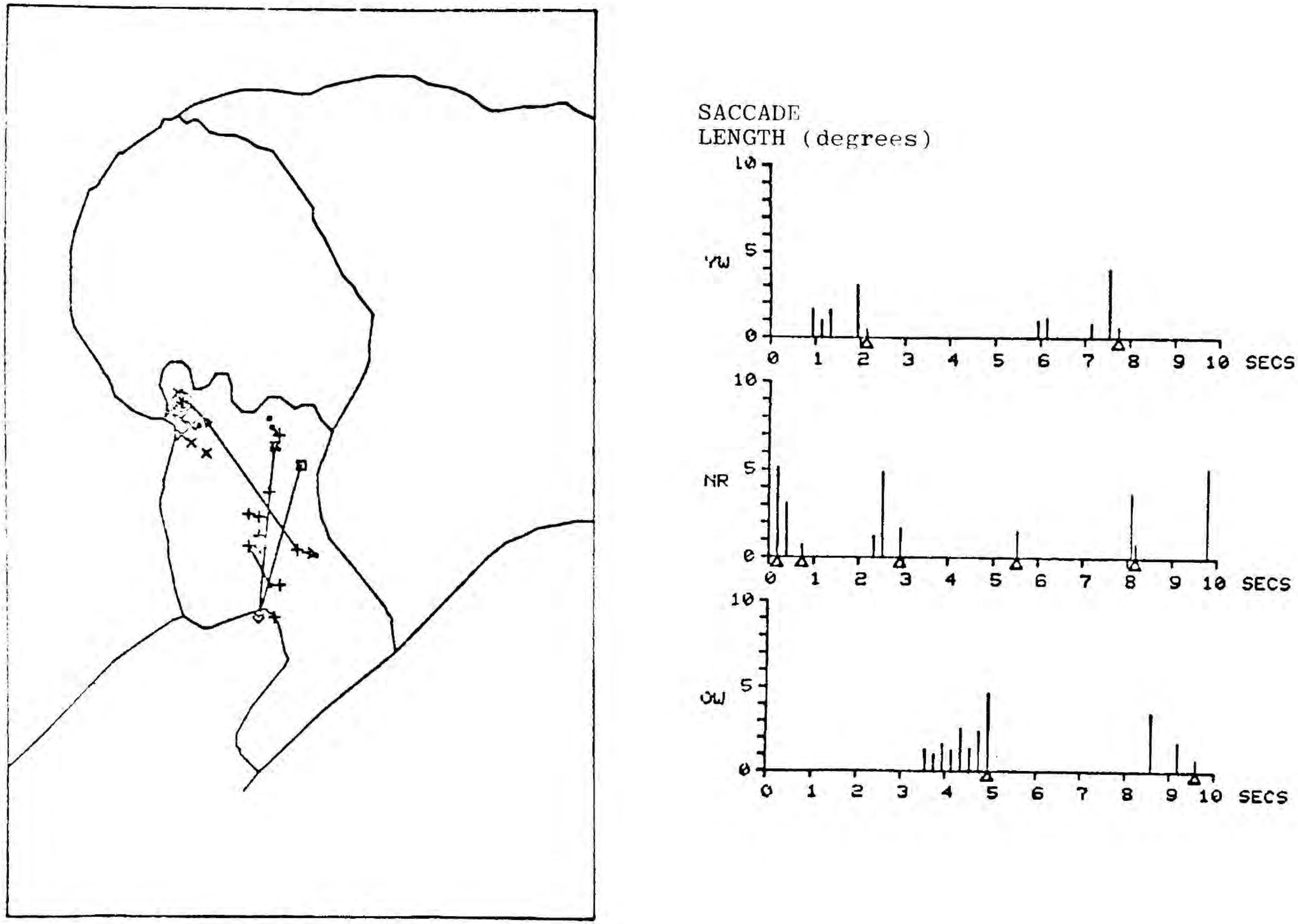
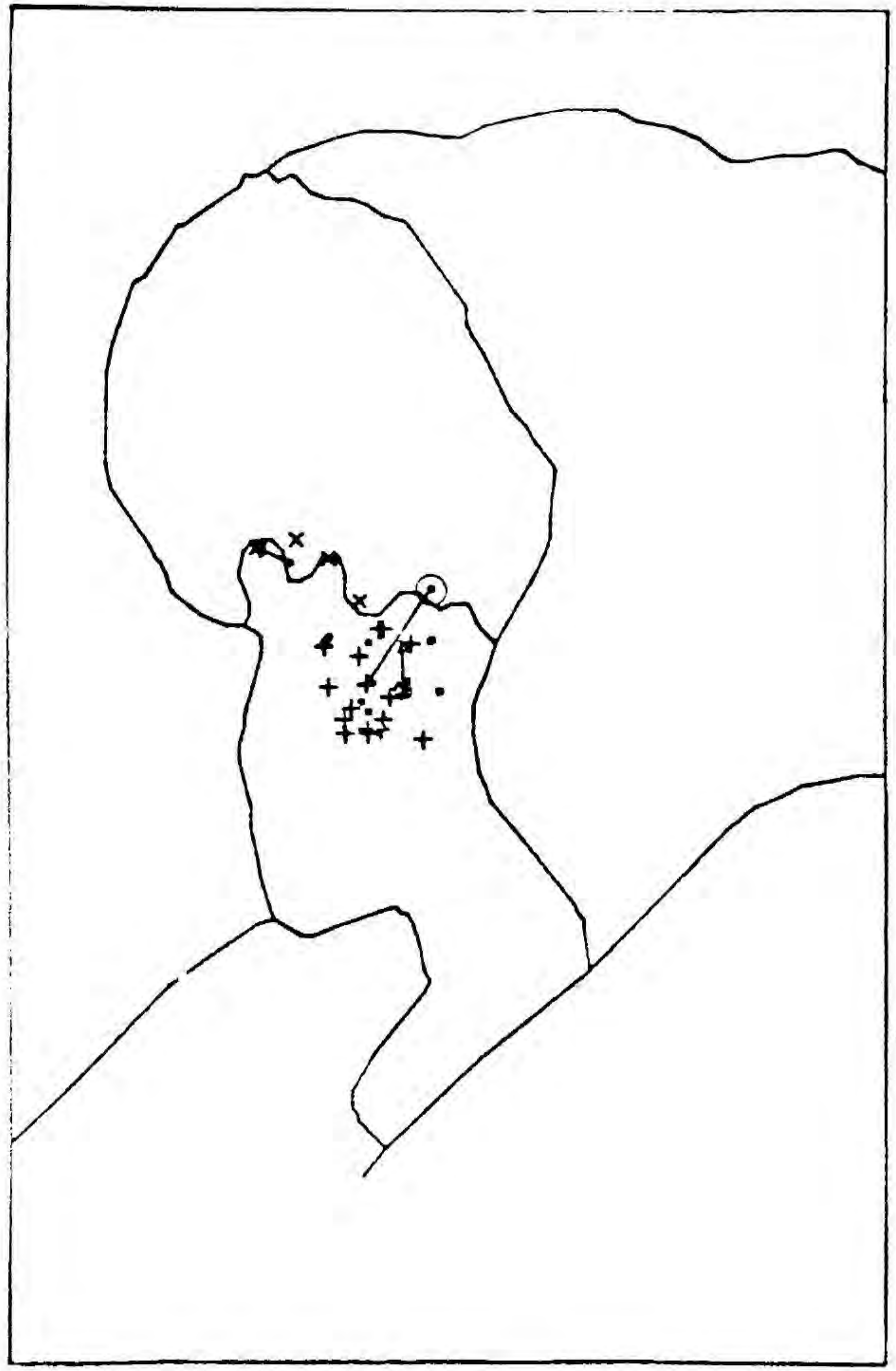


Figure F.6(a) All elements absent. Subject SW.



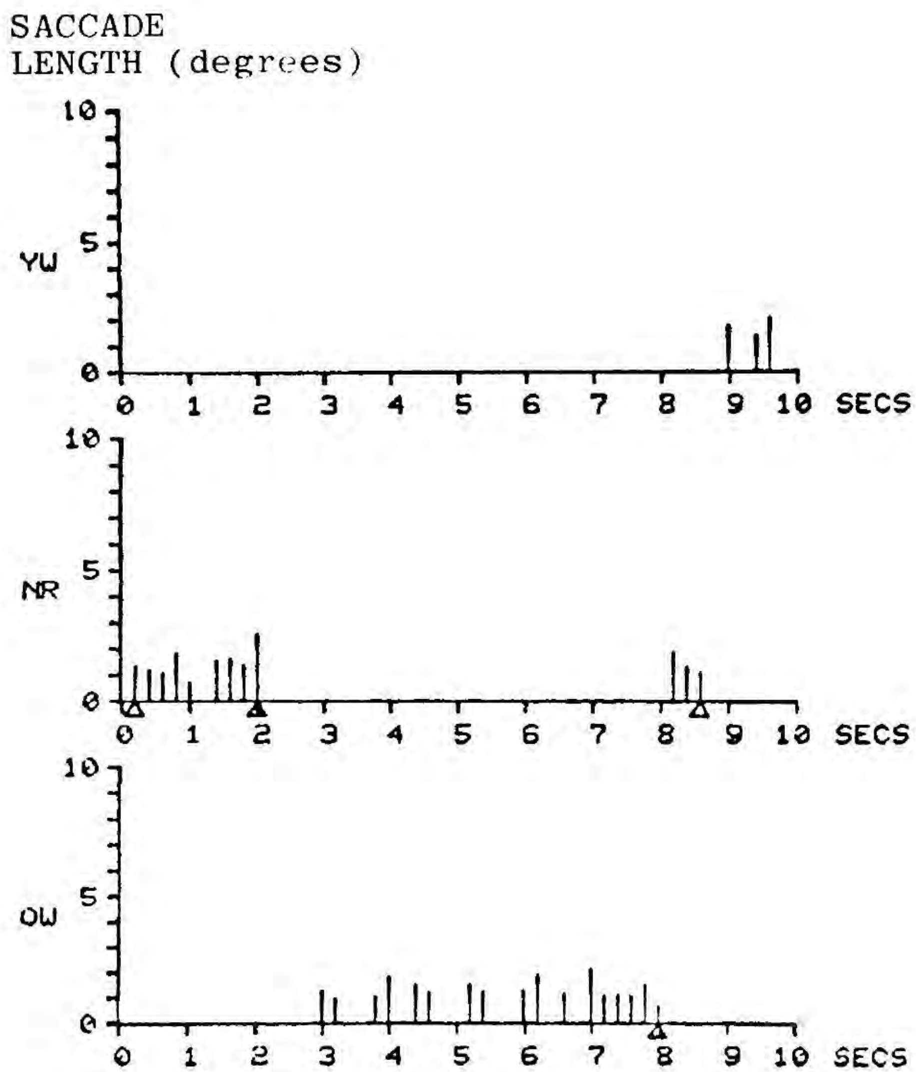
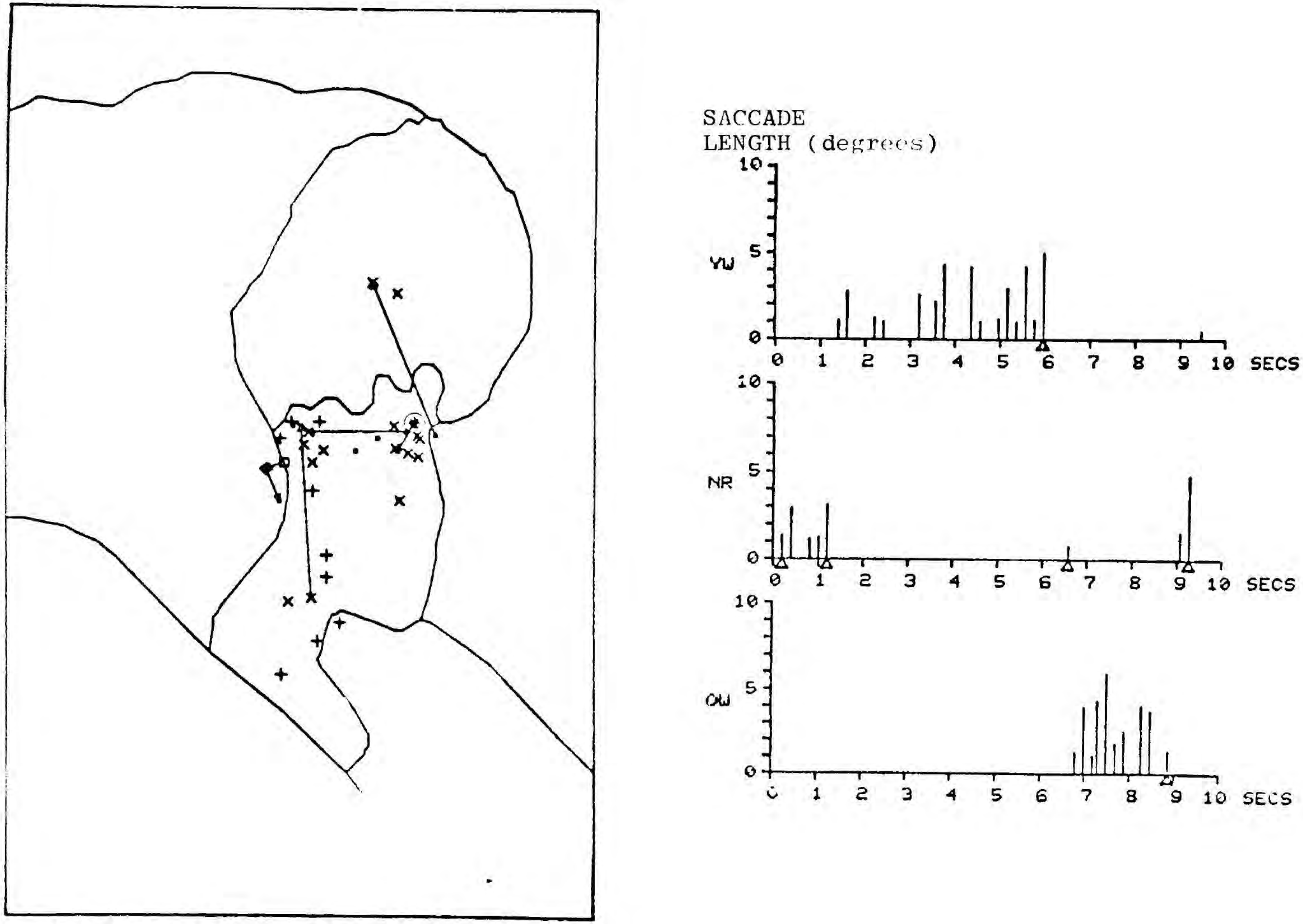
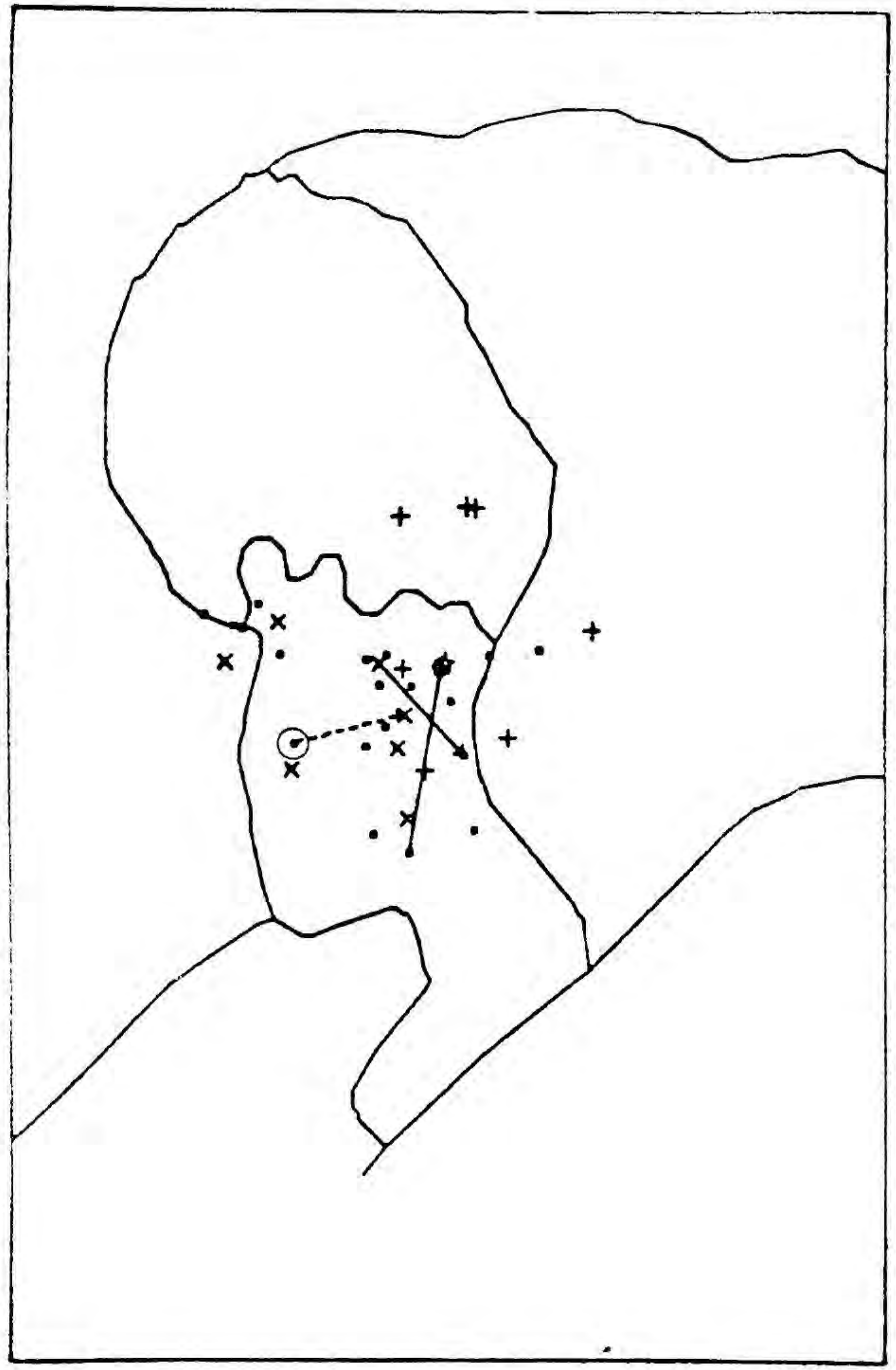
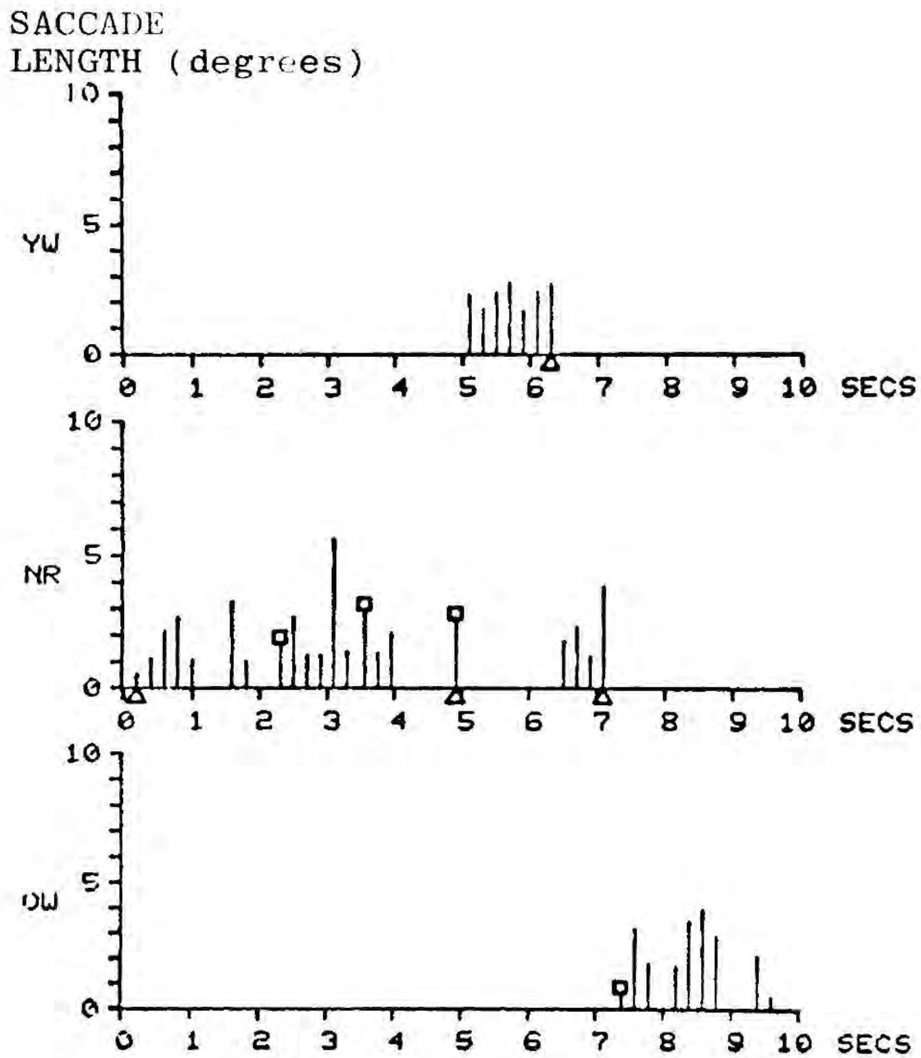


Figure F.6(b) All elements absent. Subject AS.



<u>Figure F.6(c)</u> All elements absent. Subject EP.





<u>Figure F.6(d)</u> All elements absent. Subject PS.

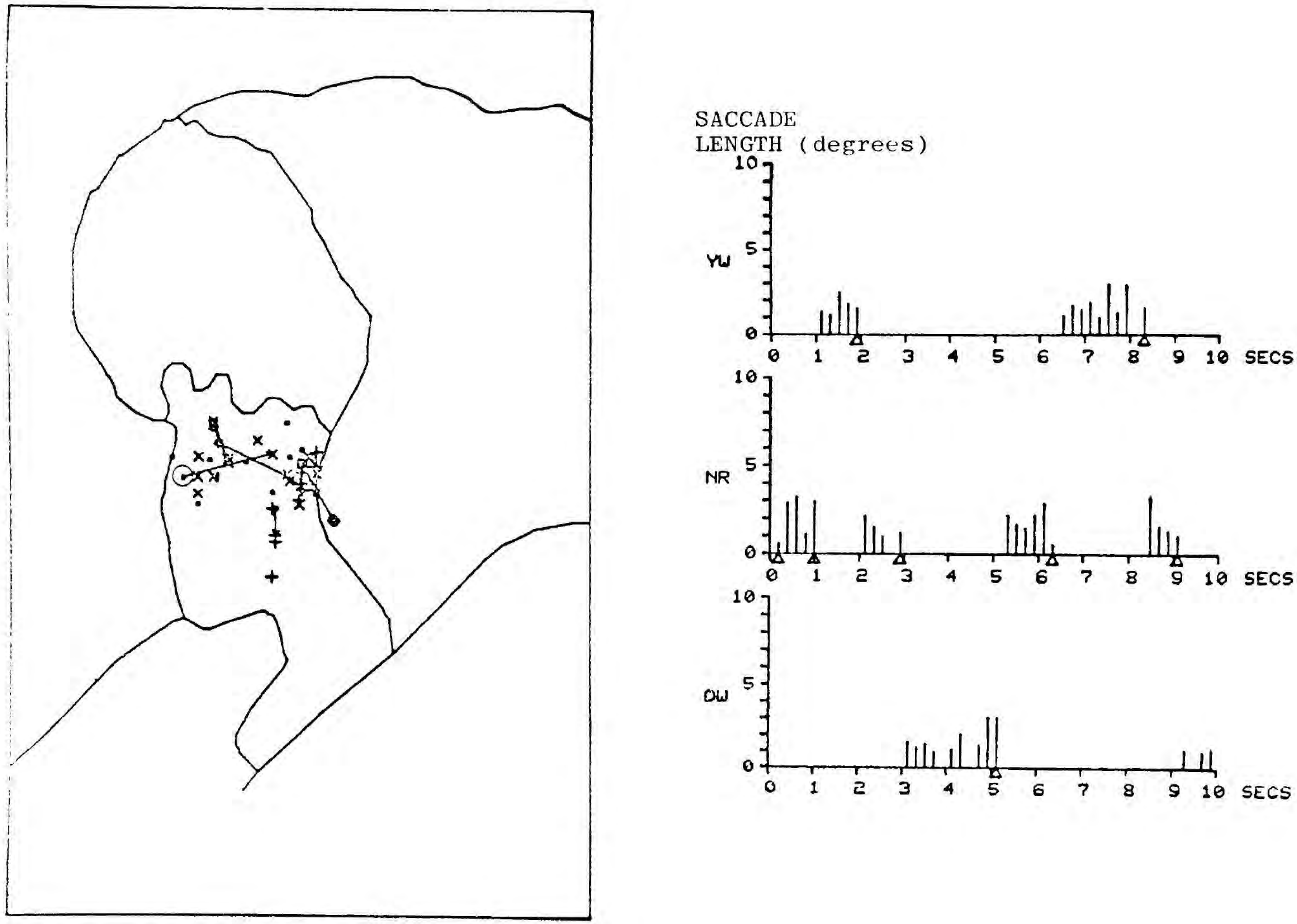


Figure F.6(e) All elements absent. Subject LS.

APPENDIX G

Eye movement strategies involved in face perception

(Reprinted from Perception, 1977, volume 6, pages 313-326)

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Abstract. Recordings were made of the eye fixations of three subjects in two tasks involving black-and-white photographs of faces. In the first task, subjects matched a test face with a previously viewed target face; in the second task, subjects compared two simultaneously presented faces. The eye movements were recorded with a corneal reflection technique.

Each subject showed an individual fixation strategy for the tasks; in particular each subject had one or more preferred facial features which were viewed foveally in both tasks. The subjects also showed some tendency to use a regular sequential pattern of eye movements. However, the sequences used differed from one task to the other. Although some aspects of the results support the scanpath hypothesis of Noton, it is suggested that an alternative interpretation is possible.

1 Introduction

Our extraordinary capacity and ability for the recognition of human faces is impressive (Ellis 1975). A face can be recognised and discriminated from a multitude of others, whereas equally complex stimuli such as inverted faces (Yin 1969) and photographic negatives of faces (Galper and Hochberg 1971) cannot be identified with the same facility.

When a face or a picture is viewed, only a small part of the stimulus will normally be looked at in foveal vision. Records of eye movements (Yarbus 1967; Mackworth and Bruner 1970) show that foveal vision is mainly reserved for elements containing essential information required by the observer during perception. In the case of face perception, most attention is paid to the eyes, nose, and mouth. The relative importance of these facial features in recognition tasks is debatable. Some workers have suggested that the eyes and the upper part of the face are most important (Goldstein and Mackenberg 1966) whilst the lower half has been favoured by Howells (1938).

Various theories of perception have emphasised the sequential nature of pattern viewing (Hebb 1949; Hochberg 1968; Noton 1970). Hochberg (1968) introduced the idea of a *schematic map*, where successive foveal glimpses are synthesised, together with the corresponding eye movement information, into an overall percept. The most explicit theory of recognition of this nature is the scanpath hypothesis (Noton 1970; Noton and Stark 1971a, 1971b). This proposes that recognition is a serial process whereby information is extracted with the use of a *fixed order* sequence of eye movements both during the time when a stimulus is first identified and memorised, and during recognition on a later occasion. Noton suggests that initially a subject learns to recognise and memorise a stimulus by representing it in memory as a sequence of memory traces which form a '*feature ring*'. These traces contain information both about sensory (visual) features and about motor (eye movement) shifts. This also describes the way information is processed during recognition, each subject having "... a fixed and characteristic path which he follows from feature to feature both when viewing the pattern and when matching it with its internal representation during recognition" (Noton and Stark 1971b). These fixed paths are called *scanpaths*. Evidence for the hypothesis occurs in an experiment (Noton and Stark 1971c) in which large, blurred, simple line drawings were presented rather close to the eyes. The authors suggest, following Hebb (1949), that under normal viewing conditions the overt eye movements of the scanpath might be replaced by internal shifts of attention. Scanpaths have been reported by Gould (1967) and more recently by Locher and Nodine (1974), although their existence has been disputed (Mackworth and Bruner 1970; Spitz 1971; Haber and Hershenson 1973).

Face perception is a situation which appears suited to an experimental investigation of the scanpath hypothesis, since the overall form of a face changes rather little from one example to another and the majority of the difference between faces may lie in the internal features. Consequently it seems plausible to suppose that, if scanpaths are being used, they will be produced whenever a face is viewed. It may be noted that Noton and Stark (1971a, 1971b) discovered scanpaths when subjects looked at an outline drawing of a face. Accordingly we studied eye movements in a facial recognition task to assess the presence or absence of scanpaths. In experiment 1 subjects were asked to make a same/different judgment about a series of faces presented sequentially after the memorisation of a standard face. In experiment 2 subjects performed a similar task in which the two faces were presented simultaneously.

2 Method

2.1 *Subjects*

Three female undergraduates served as subjects.

2.2 *Stimulus material*

Twenty-two different black-and-white photographs of human faces were selected from old department records. Any face with spectacles was excluded. For experiment 1 five sets of five faces each were chosen so that all the faces within each set appeared subjectively similar in overall characteristics. In three of the five sets, one face occurred twice. In experiment 2 a set of eight face pairs was used, each pair matched subjectively for similarity of overall type. Six pairs were of different faces whilst the remaining two pairs showed the same face duplicated.

The photographs were mounted in a 24 mm x 36 mm slide binders. The single faces were all placed centrally on the slides. The double faces, which were slightly smaller, were placed one above the other. The faces were in square frames and any excess slide area outside the frame was masked to appear black. The magnification of the faces in each experiment was adjusted so that the interocular distance was the same for each face. This had the consequence that the masked black area varied slightly from slide to slide.

2.3 *Procedure*

2.3.1 *Experiment 1.* The subject was shown a series of photographs of faces, in each case preceded by a central fixation spot. The visual angle subtended by the surround frame was 14° x 22°. The first face, which will be referred to as the *target* face, was presented for 10 s. Then a set of four *test* faces followed which had to be compared with the target face. This procedure was repeated for each of the five sets. The four comparison faces had to be judged as the same as, or different from, the target. To indicate her response, the subject was instructed to press one of two buttons as soon as her decision was made. This response terminated the slide presentation. Between each stimulus presentation a blank field was projected for 5 s followed by a further 5 s in which the fixation mark alone was shown. This was controlled by an electronic timing device which also made a record on the videotape used for recording the eye movements (see below). The five sets of stimuli were labelled A, B, C, D, E and the test stimuli within each set labelled from 1 to 4. Test faces A4, C4, and E3 were identical to the corresponding target face.

2.3.2 *Experiment 2* A series of two faces, presented simultaneously, were shown to the subject. She was instructed to indicate as quickly as possible whether the pair were the same or different. Eight stimulus slides were projected (labelled 1-8) of which two (numbers 3 and 6) were of identical pairs. Again the subject's response terminated the slide presentation. The interstimulus interval was again 5 s of a plain field followed by 5 s of a central fixation spot.

2.4 *Stimulus order*
Each subject received the different stimuli (and also the different sets of stimuli in experiment 1) in a different, randomly selected, order as follows:
Experiment 1
subject A: D4, 1, 3, 2; E3, 2, 1, 4; A2, 1, 3, 4; C2, 1, 3, 4; B4, 3, 2, 1;
subject B: C4, 3, 2, 1; D1, 4, 2, 3; A3, 1, 2, 4; B3, 1, 2, 4; E4, 3, 2, 1;
subject C: C3, 2, 1, 4; B2, 4, 1, 3; D3, 2, 4, 1; E4, 3, 2, 1; A3, 4, 2, 1.
Experiment 2
subject A: 4, 5, 7, 8, 1, 6, 3, 2;
subject B: 3, 2, 6, 8, 7, 1, 4, 5;
subject C: 6, 1, 3, 4, 8, 2, 5, 7.

2.5 *Eye movement recording*
Eye movements were measured by taking a video recording of the right eye, in which was visible the corneal reflections of four infrared marker lights (placed at the corners of the stimulus area). This technique was developed for use with infants by Haith (1969). Some theoretical considerations concerning its use have been given by Slater and Findlay (1975). For each subject, an experimental session was initiated and terminated by a recording made whilst the subject was fixating a series of positions on a calibration slide. From this calibration the true fixation positions when the subject was viewing the test slides could be assessed. The calibration was incorporated into a computer program which was used to analyse the experimental results and plot the records of fixations. The method allows eye position to be ascertained with an accuracy better than 1°, evaluated from the variation in recorded positions found when the subject makes a series of fixations and refixations. Further details are given elsewhere (Gale and Findlay, in preparation).

3 Results and discussion
3.1 *General*
The data consist of the eye fixation records, presented in figures 1 to 5, together with the values of the decision latencies given in tables 1 and 2. Detailed discussion of the results is given in later sections, but a few general points can be made here.

No incorrect decisions were made. However, the latency on a particular trial may be used to give an indication of the difficulty experienced by the subject on that trial. In each experiment, decision times for the 'same' and 'different' responses were analysed for each subject. In experiment 1 three test stimuli were the same as the corresponding target stimulus. Latencies for the 'same' responses were greater than for the 'different' responses (Mann-Whitney U test. Subject A: $U = 2$, $p < 0{\cdot}02$; subject B: $U = 10$, $p = 0{\cdot}10$; subject C: $U = 5$, $p < 0{\cdot}05$). This is possibly a reflection of the relative infrequency of the 'same' category. In experiment 2, no significant differences emerged for the two types of stimulus.

Considering the fixation records, it is apparent that the areas of the stimulus which were foveally viewed were not randomly selected. In both experiments the majority of the fixations fell in an area bounded by the eyebrows and the mouth. The finding that only a small proportion of the stimulus area received fixations is in line with the conclusions of Mackworth and Bruner (1970). Instead of utilising the time available in an attempt to fixate as much of the stimulus as possible, fixations frequently returned to parts of the stimulus which had already been viewed. This type of behaviour has been noted previously (Yarbus 1967). It is particularly apparent in the records for each subject from the 10 s viewing period of the target faces in experiment 1. One example of such a record is shown in figure 1. Another similarity between the subjects in eye movement strategy may be noted in experiment 2, where on all but two of the individual trials the first fixation made was to the upper face.

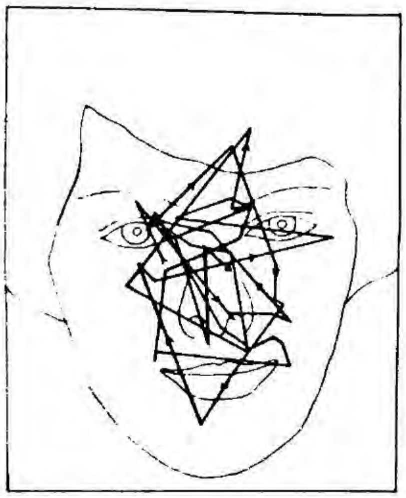

Figure 1. Example of an eye movement record (subject A, face E) in the 10 s 'memorisation' phase of experiment 1 when the target face photograph is viewed. The traced thin line shows the face outlines and the thicker line represents the saccades. Fixations occur where this line changes direction. This example was chosen because the scanning pattern can be traced without inordinate difficulty on the reproduction. Other cases show in general *more* repetition of fixations on a particular feature.

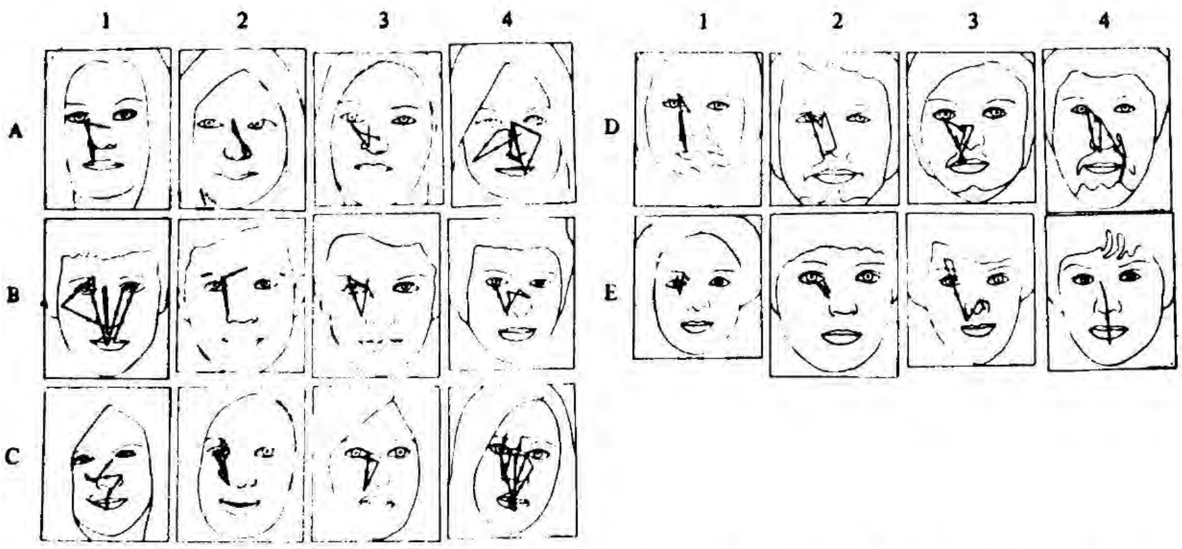

Figure 2. Eye fixations made when a subject is comparing a face presented with one previously memorised. Records are from subject A. The facial outlines were traced from the black-and-white photographs. The eye movement paths show the saccades. Fixations occur at the points where the trace changes direction.

3.2 *Scanpaths*

It was hoped that the repetitive nature of the task might induce the subject to adopt a regular strategy of eye movements. In particular, if a scanpath was involved in facial memory then it should be made manifest in these experimental situations. It is necessary to discuss certain problems inherent in the idea of scanpaths before examining the data.

The scanpath hypothesis invokes a form of visual memory in which a high level 'motor programme' sequence of eye movement commands is available. The memory consists of copy of this eye movement sequence stored together with the sensory information resulting when it is executed. In the strongest form of the theory (Noton 1970) no use is made of information in peripheral vision during the recognition phase (although peripheral vision does play a part in the memorising phase). Various modifications and extensions are suggested (Noton 1970; Noton and Stark 1971b), in particular (i) more use of peripheral vision, (ii) use of internal attention shifts rather than overt eye movements, (iii) recognition on the basis of only part of the total scanpath, and (iv) elaboration of the *feature ring* concept, that is, a unique pattern of saccades, into a *feature network* allowing multiple saccade patterns. Although in every case quite plausible, these modifications all render the hypothesis less amenable to experimental test.

Two further practical problems must be noted. The first concerns the correspondence between the proposed saccade command sequence and the actual eye movements executed. Even in the simple situation in which a subject moves his eyes voluntarily between two fixed markers the eye movement frequently takes the form of a double saccade—an initial step followed by a second corrective step. The latter

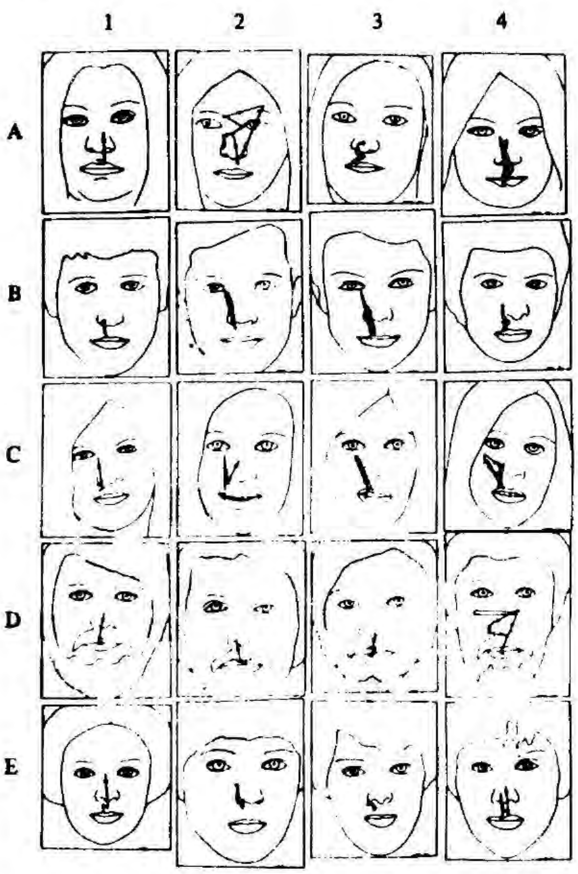

Figure 3. Eye fixations made when a subject is comparing a face presented with one previously memorised. Records are made from subject B.

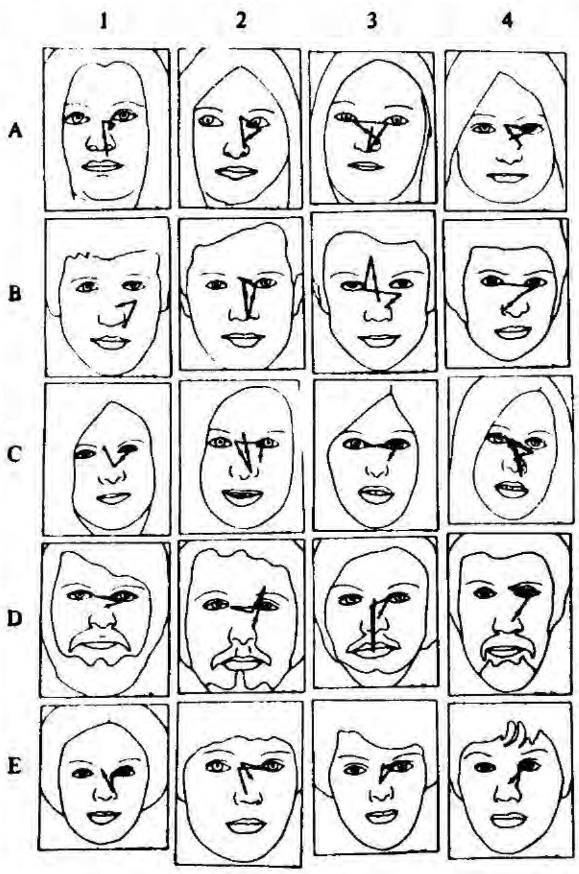

Figure 4. Eye fixations made when a subject is comparing a face presented with one previously memorised. Records are from subject C.

may be in any direction and is controlled by a peripheral feedback loop (Weber and Daroff 1971, 1972). It appears that the effector mechanism whereby an eye movement command signal is converted into an actual movement is not intrinsically very precise but achieves precision by the use of feedback mechanisms. Thus small saccades seen in records may be the result of these mechanisms. A second problem is that it is not possible to decide on a priori grounds exactly what precision is required by the scanpath hypothesis. For example a fixation which falls within, say, 2° of a pattern element may nevertheless be close enough to allow the requisite information to be extracted.

Thus there are considerable difficulties in testing the scanpath hypothesis. However, the following criteria still appear to be relevant.

1 If a task is achieved by means of scanpaths, then the eye movement sequences produced when viewing a set of identical or similar pictures should show similarity of form, allowing some latitude because of corrective saccades and the lack of precise positioning.

Although this appears to be a necessary condition for the scanpath hypothesis to be upheld, it is of course not a sufficient one. Regularities of eye movement sequence could be purely a matter of motor strategy and unrelated to any *required* sequential order in the intake of sensory information. This also applies to the assertion that the eye movement sequences in memorisation are similar to those in recognition. Further criteria must be invoked and two tentative suggestions are as follows:

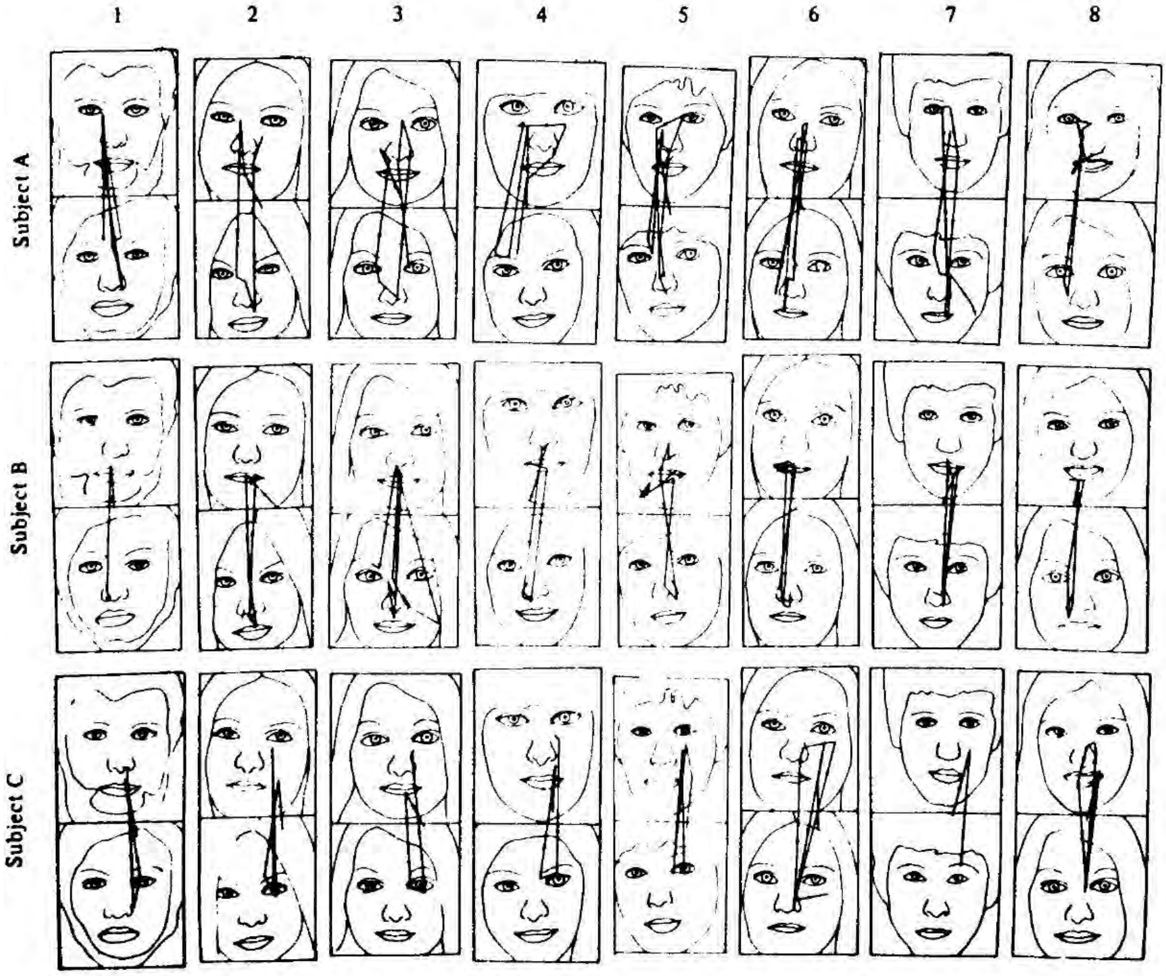

Figure 5. Eye fixations in experiment 2. Two faces were presented simultaneously and the subjects judged whether they were the same or different.

2 In cases in which the regular sequence of eye movements is not followed, if the scanpath hypothesis is correct, identification should be less accurate or else should take longer.
3 A subject should show the same scanpath when concerned with different tasks involving recognition of the same material.

For scanpaths to have any significance in everyday perception, when retinal images occur in varying sizes and projections, it must be possible for the sizes of the scanpath saccades to be scaled accordingly. Noton (1970) has suggested such a scaling process.

Table 1. Values of the decision time (s), and the cumulative length of the total saccade path travelled (°) during the course of the decision made for each stimulus in experiment 1.

Stimulus	Subject A		Subject B		Subject C	
	decision time	saccade length	decision time	saccade length	decision time	saccade length
A1	0·9	13·6	0·8	4·7	0·6	6·8
A2	0·8	9·4	3·3	28·5	0·6	9·2
A3	0·9	10·2	1·4	8·1	1·1	15·9
A4	2·5	36·5	1·9	18·6	1·0	10·7
B1	2·4	48·0	1·1	4·3	0·9	6·7
B2	0·9	12·6	1·0	11·0	1·3	15·7
B3	0·8	14·2	1·0	15·8	1·0	17·2
B4	1·5	13·6	0·8	5·5	0·8	9·1
C1	1·9	18·0	1·0	5·4	0·9	7·8
C2	1·7	22·2	1·4	14·7	1·3	16·4
C3	1·0	12·3	0·8	10·3	1·1	11·6
C4	3·6	48·8	2·8	19·0	2·2	24·2
D1	1·1	15·3	0·6	5·1	0·8	7·8
D2	1·0	16·5	0·8	4·4	0·9	15·6
D3	1·9	20·6	1·5	5·5	1·1	19·5
D4	2·0	27·9	2·5	23·8	0·7	7·6
E1	0·9	5·7	0·8	5·9	0·8	8·5
E2	0·8	7·6	0·6	4·0	0·9	12·2
E3	2·1	18·8	1·1	3·8	1·5	11·9
E4	0·6	7·7	1·2	8·9	0·9	7·2
Mean	1·5	19·0	1·3	10·4	1·1	12·1

Table 2. Values of the decision time (s) and the cumulative length of the total saccade path travelled (°) during the course of the decision made for each stimulus in experiment 2.

Stimulus	Subject A		Subject B		Subject C	
	decision time	saccade length	decision time	saccade length	decision time	saccade length
1	2·0	45·5	1·0	14·4	1·1	26·3
2	1·5	37·5	1·5	29·1	1·2	36·4
3	1·8	42·8	2·7	62·0	1·0	22·6
4	2·2	44·5	1·2	29·7	1·0	24·7
5	3·4	58·7	3·3	35·7	1·0	35·4
6	2·4	62·8	3·8	40·1	1·6	49·8
7	2·5	55·6	1·7	37·4	0·8	23·7
8	1·8	32·2	1·4	25·1	1·5	37·1
Mean	2·2	47·4	2·1	26·9	1·0	33·2

This is examined here by comparing the eye movement patterns when a single face was viewed in experiment 1, with those occurring when a pair of smaller faces was viewed in experiment 2. An additional assumption here, to be examined later, is that simultaneous face comparison evokes the same process as sequential comparison.

These criteria may now be applied to the data. The eye movement patterns during the recognition phase of experiment 1 are presented in figures 1–3, for each subject in turn. For each stimulus the method of presentation was designed to produce an initial fixation on the midnose position. In several cases this did not occur, possibly because the instructions to maintain fixation on the preliminary spot were not sufficiently emphasised. However, in the majority of cases the first fixation fell in the correct position and the following fixations may be examined for regularities.

When the next two fixations are examined, it is seen that the subject frequently, although not invariably, followed the same course as shown in detail below. The courses followed were, however, very different for each subject.

Subject A. The sequence midnose → right eye → nostril or mouth occurred on twelve occasions[1], i.e. A1, A3, B2, B3, C2, C3, D1, D2, D4, E1, E2, E3. On at least four of the remaining cases (A2, B1, D3, E4) it is possible that the same sequence was being executed less accurately.

Subject B. The sequence midnose → mouth, followed by a small saccade in the mouth or nostril area was seen on fifteen occasions, i.e. A1, A3, A4, B1, B3, B4, C1, C2, C3, D1, D2, D3, E1, E2, E4.

Subject C. The sequence, midnose → left eye → upper nose or right eye, was seen on thirteen occasions, i.e. A1, A2, A4, B4, C2, C4, D1, D2, D3, D4, E1, E3, E4, and the reverse sequence (again possibly an inaccurate execution of the original sequence) appeared on A3, B1, B2, B3, C1, E2.

These results do demonstrate that subjects will normally use a regular scanning strategy when viewing faces in a recognition task. The proportion of cases where this occurred is comparable to the figure of 65% found by Noton and Stark (1971b). To what extent is the task facilitated by the use of this procedure? The latencies for judgment in cases where the normal scanning sequence was used and those in which a different sequence occurred may be compared. Table 3 shows the mean latency in each group (the figure in brackets shows the number of cases on which it is based), and also the Mann–Whitney U statistic for the comparison. Responses to the 'same' stimuli A4, C4, and E3 have been excluded.

Although only one of the individual comparisons reached significance, the trend in each case was strongly in the direction that cases without the regular scanning sequence lead to longer latencies. Thus criterion 2 is satisfied and thus the scanpath hypothesis is upheld, although it will be argued later that this result can equally well be explained by using a feature comparison theory without use of the scanpath hypothesis.

Table 3. Mean latencies for trials in which the regular eye movement sequences is followed and for other trials. The figures in brackets show the number of cases contributing.

	Regular sequence	Other sequence	U
Subject A	0·92 (s) (11)	1·88 (s) (6)	25 ($p > 0{\cdot}05$)
Subject B	1·02 (s) (13)	1·70 (s) (4)	12½ ($p > 0{\cdot}05$)
Subject C	0·82 (s) (10)	1·02 (s) (7)	11 ($p = 0{\cdot}01$)

[1] 'Right' eye is used to refer to the eye which would be the right eye of a person viewed in an encounter. It is the eye which appears on the *left* of the reproduced drawings.

Do the regular sequences appearing in experiment 1 also appear in the simultaneous comparison task of experiment 2?

For subject A, the sequence, midnose → right eye → nostril mouth, appeared only once, in face 8 (upper). However, since the midnose position in experiment 1 is in fact the initial position it is possible that this is not an integral part of the scanpath. The sequence, left eye → nostril/mouth, can be detected in the following 2(lower), 3(lower), 7(upper), 8(upper), 8(lower).

For subject B, the sequence, midnose → mouth, occurred as follows: 2(lower), 3(lower), 4(lower), 5(lower), 6(lower). Small fixations around the mouth occurred in 3(upper), 4(upper), 5(upper), 6(upper), 7(upper), 8(upper), 8(lower). It is possible that in other cases these occurred but were not scored as separate fixations.

For subject C, the sequence, midnose → left eye → upper nose, was never seen and the second half of this sequence occurred on only one (possible) occasion, 8(upper). However, the sequence, midnose → left eye, was seen on several occasions: 1(lower), 2(lower), 3(lower), 4(lower), 5(lower), 6(lower). Thus even when the fixation sequences of experiment 1 are reduced to their smallest possible component, a sequence of two fixations, these are only observed as a small proportion of the stimuli of experiment 2. It is of note also that the regularities observed are seen to occur almost entirely on only *one* member of the pair (either the upper or the lower face). This suggests that they occurred as a consequence of a scanning strategy that took in the entire double face pattern, rather than one which had reference to the individual faces. It is also noteworthy that in all but two cases (subject B, number 1, and subject C, number 7) there were two or more large saccades which transferred fixation from one member of the pair to the other. It is clear that comparison was not effected by executing a scanpath on one face and then moving to the second and executing a scanpath on that. It does appear possible to interpret the results in terms of a sequential feature comparison process (see below).

3.3 *Features*

The term feature is widely used in current cognitive psychology although its definition is somewhat elusive. In this section an entirely pragmatic position will be taken in which the features of a face are assumed to be eyes, nose, and mouth, as in common parlance. It may be tentatively suggested that these features can only be identified in central vision (although since faces can be identified over a range of viewing distances, this requires a somewhat flexible view of 'central vision'). Thus a record of eye fixations gives a record of which features have been sampled.

Examination of the fixation records shows that fixations were confined almost entirely to the eyes-nose-mouth area in all cases. This information is tabulated in table 4. This table shows the number of occasions on which a particular feature was actually fixated, and also the proportion of occasions on which a fixation fell in a region surrounding each feature. These regions, which have approximately equal area, are nonoverlapping with the exception of the regions for the nose and mouth, which both include the area between the top of the mouth and the nostrils (see figure 6). Because of possible measurement errors, the use of the fixation region is likely to be a more meaningful measure and results from this are plotted in figure 6.

It is apparent that each subject tended to sample selectively only one, or possibly two, of the available features. However, these features, which may be called the target features, were different for each subject. Subject A used the right eye primarily, with the nostrils as subsidiary. Subject B used the mouth-nostril area, and subject C used the left eye. This selection is also borne out by the proportion of the initial fixations which fell into the appropriate regions.

Comparison of the distribution of fixations in the different target regions across the two experiments (figure 5) shows clearly that the ways fixations are distributed are very similar, in spite of the differences in absolute size of the face stimuli. For each subject the first and second most frequently fixated features of experiment 1 are also those of experiment 2. The anomalous pattern of subject C will be discussed later.

Subjects in the simultaneous comparison condition of experiment 2 appeared to be comparing individual features from each face. In all but three cases (subject B, numbers 6 and 7; subject C, number 7), at some point during comparison fixations were made on the same facial region in both faces.

Bradshaw and Wallace (1971), using data from a task similar to the present one, employing Identi-Kit® faces as stimuli, concluded that the faces were compared feature by feature (the features used were the Identi-Kit components: nose, eyes, mouth, eyebrows, hair, chin shape, and age lines). They presented evidence which supports

Table 4. Proportion of occasions in which a fixation occurred on a particular target, or target region, in each experiment (%). A diagram illustrating the way in which the target regions are articulated is shown in figure 6. It should be noted that 'left eye' is the eye that would be the left eye of a person viewed in an encounter. Thus it is the eye that appears on the *right* of each reproduced drawing. In experiment 2, fixations from both faces are included in the evaluations, other than in the scores for the first fixation.

	Fixations: subject A			Fixations: subject B			Fixations: subject C		
	on target	target region	initial	on target	target region	initial	on target	target region	initial
Experiment 1									
Left eye	10	30	10	5	10	-	75	100	85
Right eye	65	95	85	5	35	5	35	70	-
Nose	65	90	5	55	90	40	35	80	15
Mouth	40	60	-	70	100	55	5	20	-
Experiment 2									
Left eye	12	38	-	0	0	-	31	82	12
Right eye	44	82	50	6	19		0	0	-
Nose	31	62	25	69	82	12	25	38	38
Mouth	38	56	25	56	88	88	19	25	50

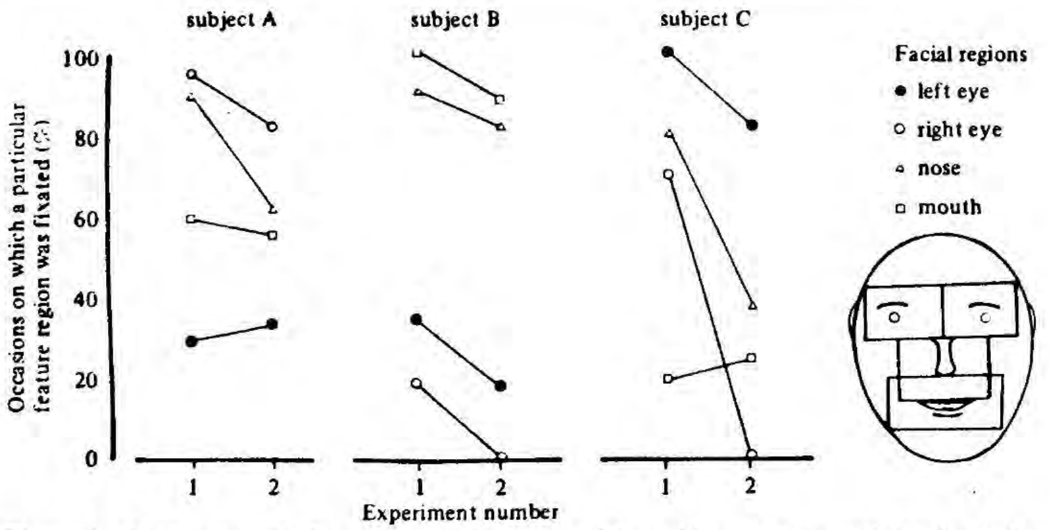

Figure 6. Comparison of the viewing strategies used by subjects in sequential and simultaneous comparison. In each experiment, the measure is the proportion of faces viewed in which a fixation is made in a particular facial region (regions as on inset figure).

a serial self-terminating scanning model whereby a decision is reached as soon as the first distinguishing feature is encountered. The present experiments broadly support Bradshaw and Wallace's findings but suggest that decisions are not always made as soon as the first feature is fixated.

3.4 *Individual differences*

Analysis of the data in tables 1 and 2 shows the following:
(i) in experiment 1, there was no significant difference in the response latencies between subjects for the test stimuli ($p > 0 \cdot 05$, Friedman test);
(ii) in experiment 2, the subjects did show different response latencies ($p < 0 \cdot 01$, Friedman test): subject C made faster decisions;
(iii) in both experiments, there was a significant difference in total saccade path length between subjects ($p < 0 \cdot 05$ in both cases, Friedman test).
The computer program also evaluated a measure of the degree to which fixations were spread over the total stimulus area. The measure, known as the repeat index, was defined as follows:

$$\text{repeat index} = \frac{(\text{number of fixations}) - (\text{number of different points fixated})}{(\text{number of fixations})}$$

This parameter varies from zero when all the fixations fall in different places, to a value near unity when all the fixations fall in the same place. The evaluation regarded a fixation falling within 1° of a previous fixation as a repeat fixation. In experiment 1 the values of the repeat index ranged from 0 to 0·7. The mean values for each subject were: subject A, 0·17; subject B, 0·32; subject C, 0·11. In experiment 2, the values ranged from 0 to 0·5, and the mean values for each subject were: subject A, 0·12, subject B, 0·21; subject C, 0·12. The intersubject difference in experiment 1 was significant ($p < 0 \cdot 01$, Friedman test), although not in experiment 2, where fewer stimuli were used.

The picture that emerges from these results is that subjects do differ in their behaviour on these tasks. Subject C demonstrated greater oculomotor efficiency, manifested in more distributed scanning and faster latencies. Similar differences between subjects have been reported by Gould and Dill (1969) in a task involving the discrimination of abstract patterns. These differences in general eye movement parameters are relatively small, however. Much more substantial differences emerged when the way in which the subjects distribute their fixations over the different regions of the face is considered. These data are presented in table 4 and figure 5.

It is clear from these results that each subject had a tendency to fixate certain areas of the face. Moreover these patterns were largely maintained from the single-face presentation to the double face. There is, however, a discrepancy in the results of subject C. Here it is found that fixations on the right eye, occurring in 70% of the stimuli in experiment 1, did not occur at all in experiment 2. The right eye is the third and last stage in the regular scanning sequence seen in experiment 1, and it appears that this part of the sequence disappeared first, possibly in the interests of a more efficient scanning strategy. The same individual patterns are also seen when the initial fixation on each trial is considered. Subject A tended to saccade initially to the right eye of the stimulus face, subject B to the nostril–mouth area, and subject C to the left eye. Subject B, unlike the other two, maintained the same trend when the last fixation prior to the decision is considered. This is still normally in the nose–mouth region. This trend was not seen in the other two subjects and results from the fact that, for the test stimuli, subject B fixated little else other than the nostrils and mouth. Subjects A and C, after fixating one eye, moved away again, either to the other eye or to the nose–mouth region.

In experiment 2, subjects B and C looked first at the upper face on all eight occasions, and subject A did this on six out of the eight occasions. Therefore subject B, who made an initial downwards saccade in experiment 1, altered the direction of her initial eye movement.

The finding that the different subjects concentrated on different facial features, if it proves to be general, could account for the controversy over which parts of the face are most important in recognition tasks. Thus the discrepancy between the findings of Goldstein and Mackenberg (1966) and those of Howells (1938) may have come about because of genuine differences in their subject groups.

3.5 *A model*

A tentative model of an aspect of face perception, supported by the evidence of this study may now be proposed. Neisser (1967) suggests that a series of foveal fixations make 'snapshots' of the visual stimulus and that the perceiver integrates these to build up representations of stable objects. This idea has been elaborated by Hochberg (1968). It represents, we believe, what is happening in the present face perception tasks. A speculative account of how the 'snapshots' are integrated is as follows.

The initial fixation permits a general gestalt to be registered. This may serve to promote the construction of a basic 'face' framework because the peripheral viewing has given the subject enough information to enable him to identify the pattern as a face. Several fixations are then made. Each part of the fact that receives high-acuity vision is perceived in detail and may then be fitted into the model which the perceiver has constructed. The additional peripheral viewing enables features of the fact to be spatially located. Undoubtedly a subject, having registered the presence of a face in his first fixation, would be likely to saccade at the feature which, for him, was the most salient and following this might well tend to saccade to the next most salient feature. Thus regular scanning sequences, similar to those of scanpath theory, might arise. However, there is a difference. The theory of Noton (1970) assumes the eye movements are controlled entirely by the internal programme working from information received at the *last* feature, whereas we are suggesting that a saccade is directed to the *next* feature, allowing some control to be exerted by visual information in peripheral vision. The regular sequence would not be essential for recognition but since it represents the optimum scanning of features it would result, as observed, in the most rapid recognition.

It may be noted that subjects often need to look foveally at only one side of the face. Since faces are approximately symmetrical it would seem plausible to propose that the perceiver, after fixating certain parts of one side of a face, assumes that the other side would be similar and therefore inserts a duplicate symmetrical feature into his internal face construct. Such a completion process seems to occur in the split brain patients studied by Levy et al (1972). If, however, the viewer subsequently fixated the actual symmetrical feature, the previous approximation could be replaced by a 'true' perceptual image.

In the face comparison task an initial face percept may possibly also be used to construct a more detailed basic face structure. New fixations from comparison faces would then lead to parts of this existing face being remodelled by the new facial features being inserted. To compare faces only a few features need to be inserted in the face frameworks but more similar faces would probably require more fixations. Also for an accurate comparison to be made, at least one feature in any comparison pair would need to be fixated foveally in both faces. This generally seems to occur in the eye movement data of figure 5.

4 Conclusions

1 Eye fixation records from facial recognition tasks show that subjects looked directly at only certain limited facial regions. This occurred both in a task in which a single face is viewed and compared with a previously memorised face, and in a task in which two faces are simultaneously viewed and a same/different comparison made.
2 The sequence of fixations for each individual subject was examined. With a particular type of stimulus, certain regularities of sequence were frequently found, allowing for some lack of precision in the eye positioning mechanism. In the sequential comparison task, trials on which the regular sequence was followed showed significantly faster responses than those in which it was not. There was little similarity between the sequence of fixations observed when a single face was viewed and that when a face pair was viewed. Although the single face results are comparable with those from which the scanpath theory of Noton and Stark was derived, it is suggested that an alternative interpretation is possible.
3 Each subject was shown to direct her gaze to one or more particular facial regions, and these could be related to the obvious 'features' of the face, i.e. eyes, nose, and mouth. The preferred features were different for each subject (subject A – right eye and nose, subject B—nose and mouth; subject C—left eye). However, the distribution of fixations on the different features in the single face task matched closely that seen on the double-face task for each subject.
4 Results from the double-face task also implicate the importance of facial features. They suggest that before a decision can be made, the same feature must be fixated on each of the faces. All subjects normally showed two or more fixations from one face to the other in this task.
5 A model of the role of eye movements in facial recognition is formulated. In this successive glances function to allow details of facial features to be entered into a general 'face' framework.
6 The present investigation has demonstrated that the study of eye movement scanning strategies involved in two-dimensional face comparison and recognition is a fruitful area of research. It is hoped that work in this field will continue.

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References

Bradshaw J L, Wallace G, 1971 "Models for the processing and identification of faces" *Perception and Psychophysics* 9 443-448
Ellis H D, 1975 "Recognizing faces" *British Journal of Psychology* 66 409-426
Galper R E, Hochberg J, 1971 "Recognition memory for photographs of faces" *American Journal of Psychology* 84 351-354
Goldstein A G, Mackenberg E J, 1966 "Recognition of human faces from isolated facial features: A developmental study" *Psychonomic Science* 6 149-150
Gould J D, 1967 "Pattern recognition and eye movement parameters" *Perception and Psychophysics* 2 399-407
Gould J D, Dill A D, 1969 "Eye movement parameters and pattern discrimination" *Perception and Psychophysics* 6 311-320
Haber R N, Hershenson M, 1973 *The Psychology of Visual Perception* (New York: Holt, Rinehart and Winston)
Haith M 1969 "Infrared television recording and measurement of ocular behaviour in the human infant" *American Psychologist* 24 279-283
Hebb D O, 1949 *The Organization of Behaviour* (New York: John Wiley)
Hochberg J, 1968 "In the mind's eye" in *Contemporary Theory and Research in Visual Perception* Ed. R N Haber (New York: Holt, Rinehart and Winston)
Howells T H, 1938 "A study of the ability to recognise faces" *Journal of Abnormal and Social Psychology* 33 124-127

Levy J, Trevarthen C, Sperry R W, 1972 "Perception of bilateral chimeric figures following hemispheric deconnection" *Brain* **95** 61-78

Locher P J, Nodine C F, 1974 "The role of scanpaths in the recognition of random shapes" *Perception and Psychophysics* **15** 308-314

Mackworth N H, Bruner J S, 1970 "How adults and children search and recognise pictures" *Human Development* **13** 149-177

Neisser U, 1967 *Cognitive Psychology* (New York: Appleton-Century-Crofts)

Noton D, 1970 "A theory of visual pattern perception" *IEEE Transactions on Systems Science and Cybernetics* **6** 349-357

Noton D, Stark L, 1971a "Eye movements and visual perception" *Scientific American* **224** June 35-43

Noton D, Stark L, 1971b "Scanpaths in saccadic eye movements whilst viewing and recognising patterns" *Vision Research* **11** 929-942

Noton D, Stark L, 1971c "Scanpaths in eye movements during pattern perception" *Science* **171** 308-311

Slater A M, Findlay J M, 1975 "The corneal reflection technique and the visual preference method: Sources of error" *Journal of Experimental Child Psychology* **20** 240-247

Spitz H H, 1971 "Scanpaths and pattern recognition" *Science* **173** 753

Weber R B, Daroff R B 1971 "The metrics of horizontal saccadic eye movement in normal humans" *Vision Research* **11** 921-928

Weber R B, Daroff R B, 1972 "Corrective movements following refixation saccades; type and control system analysis" *Vision Research* **12** 467-475

Yarbus A L 1967 *Eye Movements and Vision* (New York: Plenum Press)

Yin R K, 1969 "Looking at upside-down faces" *Journal of Experimental Psychology* **81** 141-145

R E F E R E N C E S

Adams, P.A.(1954) The effect of past experience on the perspective reversal of a tridimensional figure. Am. J. Psychol. 67, 708-710.

Adams, P.A. and Haire, M. (1958) Structural and conceptual factors in the perception of double-cube figures. Am. J. Psychol. 71, 548-556.

Adams, P.A. and Haire, M. (1959) The effect of orientation on the reversal of one cube inscribed in another. Am. J. Psychol. 72, 296-299

Albutt, M.G.V., Bamborough, P., Churcher, J., Heywood, S.P., Rice, P.D., and Salter, S.H. (1975) 'Eye movement recording by on-line analysis of television'. Unpublished manuscript. Univ. Oxford.

Allen, M.J. (1955) A simple photographic method for continuously recording vertical and horizontal eye movements. Am. J. Optom. 32, 88-92.

Alpern, M. (1969) 'Movements of the eyes'. In H. Davson (Ed.) The eye. Vol. 3: Muscular mechanisms. (2nd. Ed.) New York; Academic Press.

Ammons, R.B. (1954) Experiential factors in visual form perception: I. Review and formulation of problems. J. Genet. Psychol. 84, 3-25.

Ammons, C.H. and Ammons, R.B. (1963) Perspective reversal as affected by physical characteristics of Necker cube drawings. Proc. Montana Acad. Sci. 23, 287-302.

Ammons, R.B., Ulrich,P., and Ammons, C.H. (1959) Voluntary control of perception of depth in a two-dimensional drawing. Proc. Montana Acad. Sci. 19, 160-168.

Antes, J.R. (1974) The time course of picture viewing. J. exp. Psychol. 103 (1), 62-70.

Arnold, P., Meudell, P.R., and Pease, K.G. (1968) Influence of meaning on fragmentation of visual afterimages. Percept. mot. Skills 27, 965-966.

Artin, E. (1947) Theory of braids. Ann. Math. 48, 643-649.

Attneave, F. (1968) Triangles as ambiguous figures. Am. J. Pschol. 81, 447-453.

Attneave, F. (1971) Multistability in perception. Scient. Am. 225, 62-71.

Axelrod, S. and Thompson, L. (1962) On visual changes of reversible figures and auditory changes in meaning. Am. J. Pschol. 75, 673-674.

Baker, M.A. and Loeb, M. (1973) Implications of measurements of eye fixations for a psychophysics of form perception. Percept. Psychophys. 13 (2), 185-192.

Baker, R.J. and Nelder, J.A. (1978) The GLIM system. Generalised linear interactive modelling. (Release 3). Oxford, Royal Statistical Society.

Baldwin, H. (1967) Building better blivets. Worm Runners Digest 9, 104-106.

Barlow, H.B. (1952) Eye movements during fixation. J. Physiol. Lond. 116, 290-306.

Barlow, H.B. (1963) Slippage of contact lenses and other artefacts in relation to fading and regeneration of supposedly stable retinal images. Q. Jl exp. Psychol. 15, 36-51.

Barlow, H.B., Narasimhan, R., and Rosenfeld, A. (1972) Visual pattern analysis in machines and animals. Science, N. Y. 177, 567-575.

Bartol, C.R. and Pielstick, J.F. (1972) The effects of ambiguity, familiarisation, age and sex on stimulus preference. J. exp. child Psychol. 14, 21-29.

Bartz, A.E. (1962) Eye movement latency, duration, and response time as a function of angular displacement. J. exp. Psychol. 64 (3), 318-324.

Beardslee, D.C. and Wertheimer M. (Eds.) (1958) Readings in perception. Princeton N.J., Van Nostrand.

Bechnai, N.R.L. and Hallett, P.E. (1977) Measurement of the rotation of a disk from its elliptical projection, with an application to eye movements. J. Opt. Soc. Am. 67, 1336-1339.

Bennett, A.G. and Francis, J.L. (1962) 'The eye as an optical system'. In H. Davson (Ed.) The eye. Vol 4: Visual optics and the optical space sense. New York; Academic Press.

Bennett-Clark, H.C. and Evans, C.R. (1963) Fragmentation of patterned targets when viewed as prolonged after-images. Nature, Lond. 199, 1215-1216.

Biederman, I. (1972) Perceiving real-world scenes. Science, N.Y. 177, 77-80.

Biederman, I., Glass, A.L., and Stacy, E.W.(1973) Searching for objects in real-world scenes. J. exp. Psychol. 97 (1), 22-27.

Biederman, I., Rabinowitz, J.C., Glass, A.L., and Stacy, E.W. (1974) On the information extracted from a glance at a scene. J. exp. Psychol. 103 (3), 597-600.

Bills, A.G. (1931) Blocking: a new principle of mental fatique. Am. J. Psychol. 43, 230-245.

Bles, W. and Kapteyn, T.S. (1973) Separate recording of the movement of the human eyes during parallel swing tests. Acta Oto-Laryn. 75, 6-9.

Boring, E.G. (1930) A new ambiguous figure. Am. J. Psychol. 42, 444-445.

Boring, E.G. (1942) Sensation and perception in the history of experimental psychology. New York; Appleton-Century-Crofts.

Borsellino, A., De Marco, A., Allazetta, A., Rinesi, S., and Bartolini, B. (1972) Reversal time distribution in the perception of visual ambiguous stimuli. Kybernetik 10, 139-144.

Botha, E. (1963) Past experience and figure-ground perception. Percept. mot. Skills 16, 283-288.

Botwinick, J. (1961) Husband and father-in-law - a reversible figure. Am. J. Psychol. 74, 312-313.

Botwinick, J., Robbin, J.S., and Brinley, J.F. (1959) Reorganisation of perceptions with age. J. Geront. 14, 85-88.

Brandt, H.F. (1937) A bidimensional eye-movement camera. Am. J. Psychol. 49, 666-670.

Brewster, D. (1826) On the optical illusion of the conversion of cameos into intaglios, and of intaglios into cameos, with an account of other analogous phenomena. Edin. J. Sci. 4, 99-108.

Brewster, D. (1847) On the conversion of relief by inverted vision. Lond. Edin. Dub. Phil. Mag. 30, 432-437.

Broadbent, D.E. (1958) Perception and Communication. New York; Pergammon press.

Broadbent, D.E. (1971) Decision and stress. New York; Academic Press.

Brown, K.T. (1955) Rate of apparent change in a dynamic ambiguous figure as a function of observation time. Am. J. Psychol. 68, 358-371.

Brown, K.T. (1962) Complete interocular transfer of an adaptation process responsible for perceptual fluctuations with an ambiguous visual figure. Vision Res. 2, 469-475.

Bruner, J.S. (1974) Beyond the information given. Studies in the psychology of knowing. London, Allen and Unwin.

Bruner, J.S. and Minturn, A.L. (1955) Perceptual identification and perceptual organisation. J. gen. Psychol. 53, 21-28.

Bruner, J.S., Postman, L., and Mosteller, F. (1950) A note on the measurement of reversals of perspective. Psychometrika 15 (1), 63-72.

Bruner, J.S. and Potter, M.C. (1964) Interference in visual recognition. Science, N.Y. 144, 424-425.

Buchsbaum, M., Pfefferbaum, A., and Stillman, R. (1972) Individual differences in eye-movement patterns. Percept. mot. Skills 35, 895-901.

Bugelski, B.R. and Alampay, D.A. (1961) The role of frequency in developing perceptual sets. Can. J. Psychol. 15, 205-211.

Bullinger, A. (1974) L'enregistrement des mouvements oculaires par le reflet cornéen. Analyse des erreurs systématiques de la localisation du regard. Perception 3, 355-360.

Buswell, G. (1935) How people look at pictures. Chicago; Univ. Chicago Press.

Byford, G.H. (1963) Non-linear relations between the corneo-retinal potential and horizontal eye movements. J. Physiol., Lond. 168, 14P-15P.

Cameron, D. (1936) Studies in depression. J. Ment. Sci. 82, 148-161.

Campbell, F.W. and Robson, J.G. (1961) A fresh approach to stabilised retinal images. J. Physiol., Lond. 158, 1-11.

Campbell, F.W. and Robson, J.G. (1968) Application of fourier analysis to the visibility of gratings. J. Physiol., Lond. 197, 551-556.

Carlson, V.R. (1953) Satiation in a reversible perspective figure. J. exp. Psychol. 45 (6), 442-448.

Carmichael, L. (1951) Another hidden figure. Am. J. Psychol. 64, 137-138.

Carpenter, R.H.S. (1977) Movements of the eyes. London; Pion.

Chastain, G. and Burnham, C.A. (1975) The first glimpse determines the perception of an ambiguous figure.

Percept. Psychophys. 17 (3), 221-224.

Chiang, C. (1976) A theory of ambiguous pattern perception. Bull. math. Psychol. 38, 497-504.

Cipywnyk, D. (1959) Effect of degree of illumination on rate of ambiguous figure reversal. Can. J. Psychol. 13, 169-174.

Clark, B. (1934) A camera for simultaneous recording of horizontal and vertical movements of both eyes. Am. J. Psychol. 40, 325-326.

Clark, B.A.J. (1967) Infra-red transmission limits for welding filters. Aust. J. Optom. 50, 154-161.

Clark, B.A.J. (1968) Welding filters and thermal damage to the retina. Aust. J. Optom. 51, 91-98.

Clowes, M.B. and Ditchburn, R.W. (1959) An improved apparatus for producing a stabilised retinal image. Optica Acta 6, 128-133.

Cohen, L. (1959) Rate of apparent change of a Necker cube as a function of prior stimulation. Am. J. Psychol. 72, 327-344.

Colegate, R.L. and Hoffman, J.E. (1974) Monitoring small eye movements with averaged EOG. Bull. Psychon. Soc. 4 (2B), 149-151.

Collewijn, H., Mark, F.van der., and Jansen, T.C. (1975) Precise recording of human eye movements. Vision Res. 15, 447-450.

Coombs, C.H. (1953) 'The theory and methods of social measurement'. In L. Festinger and D. Katz (Eds.) Research methods in the behavioural sciences. New

York, Dryden Press.

Coren, S. (1971) The use of Haidinger's brushes in the study of stabilised retinal images. Behav. Res. Meth. Instru. 3 (6), 295-297.

Coren, S. and Girgus, J.S. (1978) Seeing is deceiving: The psychology of visual illusions. London; Wiley.

Coren, S. and Kaplan, C.P. (1972) Clarity of Haidinger's brushes as a function of luminance. Behav. Res. Meth. Instru. 4 (6), 341-342.

Coren, S. and Komoda, M.K. (1973) The effect of cues to llumination on apparent lightness. Am. J. Psychol. 86, 345-349.

Cormack, R.H. and Arger, R. (1968) Necker cube perspective dominance as a function of retinal disparity. Percept. mot. Skills 26, 367-370.

Cornsweet, T.N. (1956) Determination of the stimuli for involuntary drifts and saccadic eye movements. J. Opt. Soc. Am. 46, 987-993.

Cornsweet, T.N. (1970) Visual perception. New York, Academic Press.

Cornsweet, T.N. and Crane, H.D. (1967) Design of an optometer and two-dimensional eye tracker. Report No.NAS2-3517. National Aeronautics and Space Administration.

Cornsweet, T.N. and Crane, H.D. (1973) Accurate two-dimensional eye tracker using first and fourth Purkinje images. J. Opt. Soc. Am. 63, 921-928.

Cornwell, H.G. (1963) Prior experience as a determinant of figure-ground organisation. J. exp. Psychol. 65(2), 156-162.

Cornwell, H.G. (1964) Effect of training on figure-ground organisation. J. exp. Psychol. 68 (1), 108-109.

Cornwell, H.G. (1976) Necker cube reversal; sensory or psychological satiation? Percept. mot. Skills 43, 3-10.

Cowan, T.M. (1974) The theory of braids and the analysis of impossible figures. J. math. Psychol. 11 (3), 190-212.

Cowan. T. (1977) Organising the properties of impossible figures. Perception 6, 41-56.

Cowey, A. (1963) The basis of a method of perimetry with monkeys. Q. Jl exp. Psychol. 15, 81-90.

Cox, D.R. (1970) The analysis of binary data. London, Methuen.

Cox, S.G. (1973) Development of an eye point of regard recording system. Technical report No. 73120. Farnborough, Royal Aircraft Establishment.

Craske, B. and Smith, D.G. (1975) A two-dimensional eye position and movement transducer of high sensitvity and stability. Q. Jl exp. Psychol. 27, 137-140.

Dallenbach, K.M. (1951) A puzzle-picture with a new principle of concealment. Am. J. Pschol. 64, 431-433.

Davis, P.W., Lutz, J.S., Warner, A., and Iannini, A.A. (1971) Design and construction of a portable oculometer for use in transportation oriented human factors studies. DOT-TSC-OST-71-13,Cambridge, Mass., Transport Systems Centre.

Davis, J.R. and Shackel, B. (1960) Changes in the EOG potential level. Br. J. Opthalmol. 44, 606-618.

Day, R.H. and Power, R.P. (1965) Apparent reversal (oscillation) of rotary motion in depth. Pschol. Rev. 72 (2), 117-127.

Dember, W.N. (1965) The psychology of perception. New York; Holt, Rinehart and Winston.

Didday, R.L. and Arbid, M.A. (1975) Eye movements and visual perception: A 'two visual system' model. Int. J. Man-Machine Stud. 7,547-569.

Ditchburn, R.W. (1973) Eye movements and visual perception. London, Clarendon Press.

Ditchburn, R.W. and Ginsborg, B.L. (1953) Involuntary eye movements during fixation. J. Physiol., Lond. 119,

Ditchburn, R.W. and Pritchard, R.M. (1956) Stabilised interference fringes on the retina. Nature, Lond. 177,434.

Dodge, R. (1903) Five types of eye movement in the horizontal meridian plane of the field of regard. Am. J. Physiol. 8, 307-329.

Dodge, R. and Cline, T.S. (1901) The angle velocity of eye movements. Psychol. Rev. 8, 145-157.

Donahue, W.T. and Griffitts, C.K. (1931) The influence of complexity on the fluctuations of the illusions of reversible perspective. Am. J. Psychol. 43,613-617.

Dornic, S. (1967) Measurement of satiation in reversible figures. Stud. Psychol. 9 (1), 18-24.

Duncan, C.P. (1956) On the similarity between reactive inhibition and neural satiation. Am. J. Psychol. 69, 227-235.

Dutton, M.B. and Traill, P.M. (1933) A repetition of Rubin's figure-ground experiment. Br. J. Psychol. 23, 389-400.

Edwards, D.C. and Goolkasian , P.A. (1974) Peripheral vision location and kinds of complex processing. J. exp. Psychol. 102 (2), 244-249.

Ellis, S.R. and Stark, L. (1978) Eye movements during the viewing of Necker cubes. Perception 7, 575-581.

Engel, F.L. (1971) Visual conspicuity, directed attention and retinal locus. Vision Res. 11, 563-576.

Engel, W. (1930) Optische Untersuchungen am Ganzfeld. I. Die Ganzfeldanordnung. Psychol. Forsch. 13, 1-5.

Epstein, W. and De Shazo, D. (1961) Recency as a function of perceptual oscillation. Am. J. Pschol. 74, 215-223.

Epstein, W. and Rock, I. (1960) Perceptual set as an artefact of recency. Am. J. Psychol. 73, 214-228.

Evans, C.R. (1966) New approach to pattern perception. Discovery 17, 17-21.

Evans, C.R. and Marsden, R.P. (1966) A study of the effect of perfect stabilisation on some well-known visual illusions, using the after-image as a method of compensating for eye movements. Scand. J. Psychol. 23, 242-248.

Eysenck, H.K. (1952) Schizothymia-cyclothymia as a dimension of personality: II. Experimental.

J. personality 20, 345-384.

Farrow, B.J. and Santos, J.F. (1962) A note on recency and perception. Am. J. Psychol. 75, 671-673.

Fender, D.H. (1964) Contact lens stability. Biomed. Sci. Instru. 2, 43-52

Fernberger, S.W. (1950) An early example of a 'hidden-figure' picture. Am. J. Psychol. 63, 448-449.

Findlay, J.M. (1974) A simple apparatus for recording micro-saccades during visual fixation. Q. Jl exp. Psychol. 26, 167-170.

Fiorentini, A. and Ercoles, A.M. (1963) Fluctuations of response to a stabilised visual stimulus. Atti. Fond. G. Ronchi. 18, 548-560.

Fisher, G.H. (1967a) Measuring ambiguity. Am. J. Psychol. 80, 541-557.

Fisher, G.H. (1967b) Preparation of ambiguous stimulus materials. Percept. Psychophys. 2, 421-422.

Fisher, G.H. (1968a) Ambiguity of form old and new. Percept.Psychophys. 4, 189-192.

Fisher, G.H. (1968b) The frameworks for perceptual localisation. Ministry of Defence project No. 70/GEN/9617. Newcastle upon Tyne, Univ. Newcastle upon Tyne.

Fisher, G.H. (1968c) Mother, father and daughter. A three-aspect ambiguous figure. Am. J. Pschol. 81, 274-277.

Fisichelli, V.R. (1946) Effect of rotational axis and dimensional variations on the reversals of apparent movement in Lissajous figures. Am. J. Psychol. 59, 669-675.

Fisichelli, V.R. (1947) Reversible perspective in Lissajous figures; some theoretical considerations. Am. J. Psychol. 60, 240-249.

Flamm, L.E. and Bergum, B.O. (1977) Reversible perspective figures and eye movements. Percept. mot. Skills 44, 1015-1019.

Flügel, J.C. (1913a) The influence of attention in illusions of reversible perspective. Br. J. Psychol. 5,357-397.

Flügel, J.C. (1913b) Some observations on local fatique in illusions of reversible perspective. Br. J. Psychol. 6, 60-77.

Forgacs, P., Jarfas, K., and Kun, L. (1973) Recording of Forgacs' photonystagmographic method. J. Laryn. Oto. 87, 347-364.

Forgus, R.H. and Melamed, L.E. (1976) Perception: A cognitive stage approach. New York; McGraw-Hill.

Forsyth, G.H. and Huber, R.J. (1976) Selective attention in ambiguous-figure perception; an individual differences analysis. Bull. Psychon. Soc. 7 (6), 498-500.

Franks, C.M. and Lindahl, L.E.H. (1963) Extraversion and rate of fluctuation of the Necker cube. Percept. mot. Skills 16, 131-137.

Fuchs, A.F. (1971) 'The saccadic system'. in P. Bach-y-rita, Collins, C.C., and Hyde, J.E. (Eds.) The control of eye movements. New York; Academic Press.

Gaarder, K., Siverman, J., Pfefferbaum, D., Pfefferbaum, L., and King, C. (1967) Infra-red method for assessment of small and large eye movements in clinical experiments. Percept. mot. Skills 25, 473-484.

Gale, A.G. (1979) A simple oculometer and its use in visual inspection studies. Ergonomics 22, 577.

Gale, A.G., Johnson, F., and Worthington, B.S. (1978) On-line real time analysis of eye movements. J. Physiol., Lond. 276, 23P.

Gale, A.G., Johnson, F., and Worthington, B.S. (1979) 'Psychology and Radiology'. In D.J.Oborne, M.M. Gruneberg, and J.R. Eiser (Eds.) Research in psychology and medicine. Vol.1. New York; Academic Press.

Gauthier, G.M. and Volle, M. (1975) Two-dimensional eye movement monitor for clinical and laboratory recordings. Electroenceph. Clin. Neurophys. 39, 285-291.

George, R.W. (1936) The influence of the fluctuations experienced involving ambiguous figures and in binocular rivalry. J. gen. Psychol. 15, 39-61.

Gibson, E.J. (1967) Principles of perceptual learning and development. New York; Appleton-Century-Crofts.

Gibson, J. J.(1950) The perception of the visual world. Boston; Houghton- Mifflin.

Gibson, J.J. (1951)What is a form? Psychol. Rev. 58, 403-412.

Gibson, J.J. (1968) The senses considered as perceptual systems. London; Allen and Unwin.

Ginsborg, B.L. (1953) Small voluntary movements of the eye. Br. J. Opthalmol. 37, 746-754.

Girgus, J.S. (1976) A developmental study of the effect of eye movements on the processing of shape information. J. exp. Child Psychol. 22, 386-399.

Girgus, J.S. and Hochberg, J. (1970) Age differences in sequential form recognition. Psychon. Sci. 21 (4), 211-212.

Girgus, J.S. and Hochberg, J. (1972) Age differences in shape recognition through an aperture in a free viewing situation. Psychon. Sci. 28 (4), 237-238.

Girgus, J.J., Rock, I., and Egatz, R. (1977) Effect of knowledge of reversibility on reversibility of ambiguous figures. Percept. Psychophys. 22 (6), 550-556.

Glen, J.S. (1940) Ocular movements in reversibility of perspective. J. gen. Psychol. 23, 243-281.

Goldhamer, H. (1934) The influence of area, position, and brightness in the visual perception of a reversible configuration. Am. J. Psychol. 46, 189-206.

Gonshoor, A. and Malcolm, R. (1971) Effect of changes in illumination level on electro-oculography. Aerospace Med. 41, 138-140.

Gordon, K. (1905) Meaning in memory and attention.

Pschol. Rev. 10, 280-283.

Gottschaldt,K. (1929) Uber den Einfluss der Erfahrung auf die Wahrnehmung von Figuren: II. Vergleichende Untersuchung uber die Wirkung figuraler Einpragung und den Einfluss spezifischer Geschehensverlaufe auf die Auffassung optischer Komplexe. Psychol. Forsch. 12, 1-87.

Gould, J.D. (1967) Pattern recognition and eye movement parameters. Percept. Psychophys. 2 (9) , 399-407.

Gould, J.D. (1976) 'Looking at pictures'. In R.A. Monty and J.W. Senders (Eds.) Eye movements and psychological processes. New York; Lawrence Erlbaum.

Gould, J.D. and Dill, A.B. (1969) Eye movement parameters and pattern discrimination. Percept. Psychophys. 6 (5), 311-320.

Graham, C.H. (1929) Area, color, and brightness difference in a reversible configuration. J. gen. Psychol. 2, 470-481.

Gregory, R.L. (1966) Eye and brain. London, Weidenfeld and Nicolson.

Gregory, R.L. (1970) The intelligent eye. London; Weidenfeld and Nicolson.

Gregory, R.L. (1973) 'The confounded eye.' In R.L. Gregory and E.H. Gombrich (Eds) Illusion in nature and art. London; Duckworth.

Gregory, R.L. (1974) 'Choosing a paradigm for perception'. In E.C. Carterette and M.P. Friedman (Eds.) Handbook of perception. Vol. 1. Historical and philosophical roots of perception. New York; Academic Press.

Gregory, R.L. and Arnold, P. (1971) Fragmentation and closure in after-images. Vision Res. 11, 1473-1477.

Guilford, J.P. (1927) 'Fluctuations of attention' with weak visual stimuli. Am. J. Psychol. 38, 534-583.

Guilford, J.P. and Braly, K.W. (1931) An experimental test of McDougall's theory of extraversion-introversion. J.abnorm. Psychol. 25, 382-389.

Guilford, J.P. and Frederinsen, N.O. (1934) Personality traits and fluctuations of the outline cube. Am. J. Psychol. 46, 470-474.

Guilford, J.P. and Hunt, J.M. (1932) Some further experimental tests of McDougall's theory of introversion-extraversion. J. abnorm. Psychol. 26, 324-332.

Haber, R.N. (1969) Eidetic images. Scient. Am. 220 (4), 36-44.

Haber, R.N. and Hershenson, M. (1973) The psychology of visual perception. New York; Holt, Rinehart and Winston.

Haddad, G.M. and Steinman, R.M. (1973) The smallest voluntary saccade: implications for fixation. Vision Res. 13, 1075-1086.

Hagen, M.A. (1974) Picture perception: towards a theoretical model. Psychol. Bull. 81, 471-497.

Haines, J.D. (1977) Non-contacting ultrasound transducer system suitable for eye movement recording. Ultrasound Med. Biol. 3, 39-45.

Haith, M.M. (1969) Infra-red television recording and measurement of ocular behaviour in the human infant.

Am. Psychol. 24, 279-283.

Harper, R.M., Hoppenbrouwers, T., and Ross, S.A. (1976) A new technique for long term recording of eye movements in infants. Electrencephal. Clin. Neurophysiol. 40, 109-112.

Harrower, M.R. (1936) Some factors determining figure-ground articulation. Br. J. Psychol. 26, 407-424.

Harrower, M.R. (1939) Changes in figure-ground perception in patients with cortical lesions. Br. J. Psychol. 30, 47-51.

Hawkins, H.L. (1969) Parallel processing in complex visual discrimination. Percept. Psychophys. 5, 56-64.

Hayward, R. (1968) Blivets-research and development. Worm Runner's Digest 10, 89-92.

Heath, H., Ehrlich, D., and Orbach, J. (1963) Reversibility of the Necker cube: II. Effects of various activating conditions. Percept. mot. Skills 17, 539-546.

Heath, H., and Orbach, J. (1963) Reversibility of the Necker cube: IV. Responses of elderly people. Percept. mot. Skills 17, 625-626.

Hebb, D.O. (1949) The organisation of behaviour. New York; Wiley.

Hebb, D.O. (1963) The semiautonomous process: its nature and nurture. Am. Psychol. 18,16-27.

Hebb, D.O. (1966) A textbook of psychology. Philadelphia; Saunders.

Heckenmueller, E.G. (1968) 'Stabilisation of the retinal image: a review of methods, effects and theory.' In R.N. Haber (Ed.) Contemporary theory and research in visual perception. London; Holt, Rinehart and Winston.

Helmholtz, H. von. (1910) Treatise on physiological optics. Vol. 3. J.P.C. Southall (Trans. from the 1910 German edition) New York, Dover Publications.

Heywood, S (1972) Voluntary control of smooth eye movements and their velocity. Nature, Lond. 238, 408-416.

Heywood, S. and Churcher, J. (1971) Eye movements and the after-image, I. Tracking the after-image. Vision Res. 11, 1163-1168.

Heywood, S. and Churcher, J. (1972) Eye movements and the after-image, II. The effect of foveal and non-foveal after-images on saccadic behaviour. Vision Res. 12, 1033-1043.

Hill, W.E. (1915) My wife and my mother-in-law. Puck, November 6th, 11.

Hochberg, J. (1950) Figure reversal as a function of visual satiation. J. exp. Psychol. 40, 682-686.

Hochberg, J. (1968) 'In the mind's eye'. In R.N. Haber (Ed.) Contemporary theory and research in visual perception. New York; Holt, Rinehart and Winston.

Hochberg, J (1970a) 'Attention, organisation, and consciousness'. In D.L. Mostofsky (Ed.) Attention: Contemporary theory and analysis. New York; Appleton-Century-Crofts

Hochberg, J. (1970b) 'Components of literacy: speculations and exploratory research'. In H. Levin and J. Williams (Eds.) Basic studies on reading. New York; Basic Books.

Hochberg, J. (1974) 'Organisation and the Gestalt tradition'.

In E.C. Carterette and M.P. Friedman (Eds.) Handbook of perception. Vol. 1. Historical and Philosophical roots of perception. New York; Academic Press.

Hochberg, J. and McAlister, E. (1953) A quantitative approach to figural 'goodness'. J. exp. Psychol. 46(5), 361-364.

Holcomb, J.M., Holcomb, H.H., and De La Pena, A. (1977) Selective attention and eye movements while viewing reversible figures. Percept. mot. Skills 44, 639-644.

Holt, G.L. and Matson, J.L. (1974) Necker cube reversals as a function of age and I.Q.. Bull.Psychon. Soc. 4(5B), 519-521.

Holt, G.L. and Matson, J.L. (1976) The effects of age on perceptual changes using two perspectives of the Necker cube. Bull.Psychon. Soc. 8 (1), 4-6.

Hord, D. (1975) Common mode rejection techniques in conjugate eye movement recording during sleep. Pschophysiol. 12, 354-355.

Howard, I.P. (1961) An investigation of a satiation process in the reversible perspective of revolving skeletal shapes. Q. Jl exp. Psychol. 13, 19-33.

Howells, T.J. (1938) A study of the ability to recognise faces. J.abnorm. Psychol. 33, 124-127.

Hubel, D.H. and Wiesel, T.N. (1962) Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. J. Physiol., Lond. 160, 106-154.

Hubel, D.H. and Wiesel, T.N. (1968) Receptive fields and functional architecture of monkey striate cortex. J. Physiol., Lond. 195, 215-243.

Hunt, J. McV. and Guilford, J.P. (1933) Fluctuation of an ambiguous figure in dementia praecox and in manic depressive patients. J. abnorm. Psychol. 27, 443-452.

Ikeda, M. and Takeuchi, T. (1975) Influence of foveal load on the functional visual field. Percept. Psychophys. 18 (4), 255-260.

Jackson, D.N. (1954) A further examination of the role of autism in a visual figure-ground relationship. J. Psychol. 38, 339-357.

James, W. (1891) Principles of psychology. Vol. 2. London; Macmillam.

Jasper, H.H. and Walker, R.Y. (1931) The Iowa eye-movement camera. Science, N.Y., 74, 291-294.

Jastrow, J. (1900) Fact and fable in psychology. Boston; Houghton Mifflin.

Jeannerod, M., Gerin, P., and Rougier, J. (1966) Enregistrement bidimensional des mouvements et des pauses oculaires, a propos d'une nouvelle methode. Rev. Oto-Neuro-Opthal. 38, 51-53.

Jones, R. (1973) Two dimensional eye movement recording using a photo-electric matrix method. Vision Res. 13, 425-431.

Julesz, B. (1974) Cooperative phenomena in binocular depth perception. Am. Sci. 62, 32-43.

Kaufman, L. and Richards, W. (1969) Spontaneous fixation tendencies for visual forms. Percept. Psychophys. 5 (2), 85-88.

Kawabata, N., Yamagami, K., and Noaki, M. (1978) Visual fixation points and depth perception. Vision Res.

18, 853-854.

Kennedy, J.M. (1973) Misunderstandings of figure and ground. Scand. J. Psychol. 14, 207-209.

Kennedy, J.M. (1974) A psychology of picture perception. San Francisco; Jossey-Bass.

Kirsch, R.A. (1964) Computer interpretation of English language text and picture patterns. IEEE Trans. Electron. Comput.EC-13, 363-376.

Koffka, K. (1935) Principles of Gestalt psychology. Harcourt; Brace and Co.

Köhler, W. (1920) Die physischen Gestalten in Ruhe und im stationaren Zustand, Eine naturphilosophische Untersuchung, Erlangen. In W.D. Ellis (Ed.)(1950)A source book of Gestalt psychology. London; Routledge and Kegan Paul.

Köhler, W. (1965) Unsolved problems in the field of figural after-effects. Psychol. Rec. 15, 63-83.

Köhler, W. and Wallach, H. (1944) Figural after-effects: an investigation of visual processes. Proc. Am. Phil. Soc. 88, 269-357.

Kolder, H. (1959) Spontane und experimentelle Anderungen des Bestandpotentials des menschlichen Auges. Pflugers Arch. Ges. Physiol. 268, 258-272.

Kolers, P.A. (1964a)Apparent movement of a Necker cube. Am. J. Psychol. 77, 220- 230.

Kolers, P.A. (1964b) The boys from Syracuse: Another ambiguous figure. Am. J. Psychol. 77, 671-672.

Kornmüller, A.E. (1930) Eine experimentelle Anasthesie der ausseren ugenmuskeln am Menschen und ihre Auswirkungen. J. f. Psychol. u. Neur. 41, 354-366.

Kris, C.(1958) Corneo-fundal potential variations during light and dark adaptation. Nature, Lond. 182, 1027-1028.

Kundel, H.L. and Nodine, C.F. (1973) A computer system for processing eye-movement records. Behav. Res. Meth. Instru. 5, 147-152.

Künnapas, T. (1957) Experiments on figural dominance. J. exp. Psychol. 53 (1), 31-39.

Künnapas, T. (1961) Measurement of the intensity of an underlying figural process: a methodological study. Scand. J. Psychol. 2, 174-184.

Künnapas, T. (1966) Intensity of the underlying process. Percept. Psychophys. 1, 288-292.

Lambert, R.H., Monty, R.A., and Hall, R.J. (1974) High-speed data processing and unobtrusive monitoring of eye movements. Behav. Res. Meth. Instru. 6, 525-530.

Lancaster, W.B. (1941) Fifty years experience in ocular motility-I. Am. J. Opthal. 24, 485-495.

Lashley, K.S., Chow, K.L., and Semmes, J. (1951) An examination of the electric field theory of cerebral integration. Psychol. Rev. 58, 123-136.

Lechelt, E.C. (1976) Time estimation and reproduction under conditions of differential perceptual oscillation. Percept. mot. Skills 42, 1235-1241.

Leeper, R. (1935) A study of a neglected portion of the field of learning-the development of sensory organisation. J. genet. Psychol. 46, 41-74.

Leppmann, P.K. and Mefferd, R.B.Jr. (1968) Validity of perceptual reports of experienced and inexperienced observers. Percept. mot. Skills 26, 1167-1172.

Levelt, W.J.M. (1967) Note on the distribution of dominance times in binocular rivalry. Br. J. Psychol.

58, 143-145.

Liebmann, S. (1927) Ueber das Verhalten farbiger Formen bei Helligkeitsgleichheit von Figur und Grund. Psychol. Forsch. 9, 300-353.

Lindauer, M.S. (1969) Set and different degrees of ambiguity of the 'wife and mother-in-law' figures. Percept. mot. Skills 29, 911-913.

Lindauer, M.S. and Baust, R.F. (1974) Comparisons between 25 reversible and ambiguous figures on measures of latency, duration, and fluctuation. Behav. Res. Meth. Instru. 6, 1-9.

Lindauer, M.S. and Lindauer, J.G. (1970) Brightness differences and the perception of figure-ground. J. exp. Psychol. 84, 291-295.

Lindsay, P.H. and Norman, D.A. (1972) Human information processing: an introduction to psychology. New York; Academic Press.

Lippold, O.C.J. and Shaw, J.C. (1971) Alpha rhythm in the blind. Nature, Lond. 232, 134.

Littman, D. and Becklen, R. (1976) Selective looking with minimal eye movements. Percept. Psychophys. 20 (1), 77-79.

Locher, J.L.(Ed.) (1971) The world of M.C. Escher. New York; Abrams.

Locher, P.J. and Nodine, C.F. (1972) The role of scanpaths in the recognition of random shapes. Percept. Psychophys. 15 (2), 308-314.

Lockhead, G.R. (1972) Processing of dimensional stimuli: a note. Psychol. Rev. 79 (5), 410-419.

Loeb, J (1887) Ueber die optische Inversion ebener Linearzeichnungen bei ein augiger Betrachtung. Pflugers Arch. 40, 274-282.

Loftus, G.R. (1972) Eye fixations and recognition memory for pictures. Cogn. Psychol. 3, 525-551.

Lord, M.P. and Wright, W.D. (1950) The investigation of eye movements. Rept. Progr. Phys. 13, 1-23.

Luria, A.R. (1973) The working brain. An introduction to neuropsychology. B. Haigh (Trans.) London; Penquin Books.

Mackinnon, G.E. (1971) Steadily fixated figures and prolonged afterimages: Further evidence that fragmentation occurs non-randomly. Can. J. Psychol. 25, 384-394.

Mackworth, N.H. (1965) Visual noise causes tunnel vision. Psychon. Sci. 3,67-68.

Mackworth, N.H. (1967) A stand camera for line-of-sight recording. Percept. Psychophys. 2, 119-127.

Mackworth, N.H. (1968) The wide angle reflection eye camera for visual choice and pupil size. Percept. Psychophys. 3 (1a), 32-34.

Mackworth, N.H. (1976) 'Stimulus density limits the useful field of view'. In R.A. Monty and J.W. Senders (Eds.) Eye movements and psychological processes. New York; Wiley.

Mackworth, N.H. and Bruner, J.S. (1970) How adults and children search and recognise pictures. Hum. Dev. 13, 149-177.

Mackworth, J.F. and Mackworth, N.H. (1958) Eye fixations recorded on changing visual scenes by the television eye-marker. J. Opt. Soc. Am. 48, 439-445.

Mackworth, N.H. and Morandi, A.J. (1967) The gaze selects informative details within pictures. Percept. Psychophys. 2 (11), 547-552.

Mackworth, N.H. and Otto, D.A. (1970) Habituation of the visual orienting response in young children. Percept. Psychophys. 7 (3), 173-178.

Mackworth, N.H. and Thomas, E.L. (1962) Head-mounted eye-marker camera. J. Opt. Soc. Am. 52, 713-716.

Maffei, L. and Fiorentini, A. (1973) The visual cortex as a spatial frequency analyser. Vision Res. 13, 1255-1267.

Magnussen, S. (1970) Reversibility of perspective in normal and stabilised viewing. Scand. J. Psychol. 11, 153-156.

Mandler, J.M. and Parker, R.E. (1976) Memory for descriptive and spatial information in complex pictures. J. exp. Psychol.: Hum. Learning & Memory 2 (1), 38-48.

Marg, E. (1951) Development of electro-oculography - standing potential of the eye in registration of eye movement. AMA Arch. Opthal. 45, 169.

Martin, J.N.T. (1967)The perception of reversible perspective figures. Papers in Psychol. 1 (2), 70-76.

Martin, J.N.T. (1971) 'Analysis of reversals of ambiguous perspective figures as time series of events'. Unpublished Ph.D. Thesis, London, Bikbeck College.

Masterman, B. and Kennedy, J.M. (1975) Building the Devil's tuning fork. Perception 4, 107-109.

Matin, L. (1976) A possible hybrid mechanism for modification of visual direction associated with eye movements: the paralysed eye experiment reconsidered. Perception 5, 233-239.

Matin, L. and Pearce, D.G. (1964) Three dimensional recording of rotational eye movements by a new contact lens technique. Biomed. Sci. Instru. 2, 79-95.

McDougall, W. (1902) The phsiological factors of the attention process. (I). Mind 11, 316-351.

McDougall, W. (1903) The physiological factors of the attention process. (III). Mind 12, 473-488.

McDougall, W. (1906) The physiological factors of the attention process. (IV). Mind 15, 329-359.

McDougall, W. (1926) An outline of abnormal psychology. London, Methuen.

McDougall, W. (1929) The chemical theory of temperament applied to introversion and extraversion. J. abnorm. Psychol. 24, 293-309.

McEwen, W.K. and Goodner, E.K. (1969) 'Secretion of tears and blinking'. In H. Davson (Ed.) The eye. Vol. 3. Muscular mechanisms (2nd. Ed.) New York;Academic Press.

McFarland J.H. (1968) 'Parts' of perceived forms: new evidence. Percept. Psychophys. 3 (2a), 118-120.

McMurray, J.G. (1954) Visual perception in exogenous and endogenous mentally retarded children. Am. J.ment. Defic.

58, 659-663.

Mefferd, R.B.Jr. (1968a) Perceptual fluctuations involving orientation and organisation. Percept. mot. Skills 27, 827-834.

Mefferd, R.B.Jr. (1968b) Perception of depth in rotating objects: 7. Influence of attributes of depth on stereokinetic percepts. Percept. mot. Skills 27, 1179-1193.

Mefferd, R.B.Jr. and Wieland, B.A. (1968) Apparent-size apparent distance relationships in flat stimuli. Percept. mot. Skills 26, 959-966.

Mefferd, R.B.Jr., Wieland, B.A., Greenstein, D.G., and Leppmann, P.K. (1968) Effects of pretraining and instructions on validity of perceptual reports by inexperienced observers. Percept. mot. Skills 27, 1003-1006.

Merchant,J. (1969) Laboratory Oculometer. NASA CR-1422, National Aeronautics and Space Administration.

Merchant, J.(1974) Fixation point measurement by the oculometer technique. Optical Eng. 13(4), 339-342.

Merchant, J. (1977) Flash upon the inward eye. New Scientist 74 (1047), 81-83.

Merchant, J., Morrissette, R., and Porterfield, J.L. (1974) remote measurement of eye direction allowing subject motion over one cubic foot. IEEE Trans. Biomed. Eng. BME-21 (4), 309-317.

Metzger, W. (1930) Optische Untersuchungen am Ganzfeld. II. Zur Phaenomenologie des homogenen Ganzfelds.Psychol.

Forsh. 13, 6-29.

Meyers, I.L. (1929) Electronystagmography: graphic study of action currents in nystagmus. Arch. Neurol. Psychiat. 21, 901-918.

Middleton, D.B., Hurt, G.J., Wise, M.A., and Holt, J.D. (1977) Description and flight tests of an oculometer. NASA-TN-D-8419. National Aeronautics and Space Administration.

Miles, W.R. and Shen, F. (1925) Photographic recording of eye movements in the reading of Chinese in vertical and horizontal axes: method and preliminary results. J. exp. Psychol. 8 , 344-362.

Miller, G.A. (1956) The magical number seven. Psychol. Rev. 63(2), 81-97.

Miller, J.E. (1958) Electromyographic pattern of saccadic eye movements. J. Opthal. 46, 183-186.

Miller, G.A., Galanter, E., and Pribram, K.H. (1960) Plans and the structure of behaviour. London, Holt, Rinehart and Winston.

Milner, P.M. (1957) The cell assembly: mark II. Psychol. Rev. 64 (4), 242-252.

Mitrani, L., Yakimoff, N., and Mateef, S.L. (1972) Combined photoelectric method for detecting eye movements. Vision Res. 12, 2145.

Monnier, M. and Hufschmidt, H.J. (1951) Das Elektro-Oculogramm und Elektro-Nystamogramm beim Menschen. Helv. Physiol. Acta. 9, 348-366.

Monty, R.A. (1975) An advanced eye-movement measuring and recording system, Am. Psychol. 30, 331-335.

Monty, R.A. and Senders, J.W. (Eds.) (1976) Eye movements and psychological processes. New York; Lawrence Erlbaum.

Muensterberg, H. (1925) Psychology: general and applied. London; Appleton.

Mull, H.K., Armstrong, G., and Telfer, B. (1956) The effect of brightness upon reversible perspectives and retinal rivalry. Am. J. Psychol. 69, 123-125.

Mull, H.K., Arp, K., and Carlin, P. (1952) Indications of a central factor in the uncontrolled and controlled shifts in cube perception. Am. J. Psychol. 65, 89-90.

Mull, H.K., Ord, N., and Locke, N. (1954) The effect of two brightness factors upon the rate of fluctuation of reversible perspectives. Am. J. Psychol. 67, 341-342.

Murray, F.S. and Ragland, M.V. (1976) Effects of hue, brightness, contrast with background, and observation time on figural dominance in ambiguous patterns. Percept. Psychophys. 20 (2), 108-112.

Nachmias, J. (1959) Two-dimensional motion of the retinal image during monocular fixation. J. Opt. Soc. Am. 49, 901-908.

Nayrac, P., Milbled, G., Parqet, Ph-J., Leclercq, M., and Dhedin, G. (1969) Un nouveau procédé d'enregistrement des mouvements oculaires. Application aux tests de tracking. Lille Medical 14 (6), 685-687.

Necker, L.A. (1832) Observations on some remarkable phenomena seen in Swizerland; and an optical phenomenon which occurs on viewing a crystal or geometrical solid. Phil. Mag.

3 ser.: 1, 329-343.

Neisser, U. (1967) Cognitive psychology. New York, Appleton-Century-Crofts.

Neisser, U. (1976) Cognition and reality. Principles and implications of cognitive psychology. San Francisco, Freeman.

Newbigging, P.L. (1953) The relationship between rate of reversal of figures of reversible perspective and empathy. Can. J. Psychol. 7, 172-176.

Newell, A., Shaw, J.C., and Simon, H.A. (1960) Report on a general problem-solving programme. Proc. Int. Conf. Inf. Process. London, Butterworth.

Norman, D.A. and Rumelhart, D.E. (1975) Explorations in cognition. San Francisco, Freeman.

Noton, D. and Stark, L. (1971a) Eye movements and visual perception. Scient.Am. 224, 35-43.

Noton, D. and Stark. L. (1971b) Scanpaths in saccadic eye movements while viewing and recognising patterns. Vision Res. 11, 929-942.

Noton, D. and Stark. L. (1971c) Scanpaths in eye movements during pattern perception. Science, N.Y. 171, 308-311.

Ohtani, A., Kuchinomachi, Y., and Yagi, A. (1974) A simple device for detecting saccades and judging their intervals. Behav. Res. Meth. Instru. 6, 547-549.

Olson, R. and Orbach, J. (1966) reversibility of the Necker cube: VIII. Parts of the figure contributing to the perception of reversals. Percept. mot. Skills 22, 623-629.

Orbach, J., Ehrlich, D., and Heath, H. (1963) Reversibility of the Necker cube;I. An examination of the concept of 'satiation of orientation'. Percept. mot. Skills 17, 439-458.

Orbach, J., Ehrlich, D., and Vainstein, E. (1963) Reversibility of the Necker cube; III. Effects of interpolation on reversal rate of the cube presented repetitively. Percept. mot. Skills 17, 571-582.

Orbach, J. and Olson, R. (1969) Perceptual reversals, eye-blinks and preferred orientation. Percept. mot. Skills 29, 902.

Orbach, J. and Zucker, E. (1964) Reversibility of the Necker cube: IV. Effect of movement of the figure on the perception of reversals. Percept. mot. Skills 18, 945-951.

Orbach, J. and Zucker, E. (1965) Reversibility of the Necker cube; VI. Effects of interpolating a non-reversing cube. Percept. mot. Skills 20, 470-472.

Orbach, J., Zucker, E., and Olson, R. (1966) Reversibility of the Necker cube: VII. Reversal rate as a function of figure-on and figure-off durations. Percept. mot. Skills 22, 615-618.

Orschansky, J. (1898) Eine Methode die Augenbewegungen direkt zu untersuchen (Ophthalmographie). Zentalbl. Physiol. 12, 785-790.

Osgood, C. (1953) Method and theory in experimental psychology. New York, Oxford Univ. Press.

Oyama, T. (1960) Figure-ground dominance as a function of sector angle, brightness, hue and orientation. J. exp.

Psychol. 60 (5), 299-305.

OyamA, T. and Torii, S. (1955) Experimental studies of figure-ground reversal: I. The effects of area, voluntary control and prolonged observation in continuous presentation. Jap. J. Psychol. 26, 178-188.

Pastore, N. (1949) Need as a determinant in perception. J. Psychol. 28, 457-475.

Peeke, S.C. and Stone, G.C. (1973) Focal and nonfocal processing of color and form. Percept. Psychophys. 14 (1), 71-80.

Pelton, L.H. (1969) Reversals in the momentary absence of percepts. Percept. mot. Skills 29, 677-678.

Pelton, L.H. and Solley, C.M. (1968) Acceleration of reversals of a Necker cube. Am. J. Psychol. 81, 585-588.

Pelton, L.H., Solley, C.M., and Brent, S.B. (1969) Stability and attraction of perceptual organisations in the reversible figure-ground phenomenon. Percept. mot. Skills. 28, 983-991.

Penrose, L.S. and Penrose, R. (1958) Impossible objects: a special type of visual illusion. Br. J. Psychol. 49, 31-33.

Pheiffer, C.H., Eure, S.B., and Hamilton, C.B. (1956) Reversible figures and eye movements. Am. J. Psychol. 69, 452-455.

Philip, B.R. (1953) Reversals in the perception of Lissajous figures by psychotics. Can. J. Psychol. 7, 115-125.

Philip, B.R. and Fisichelli, V.R. (1945) Effect of speed of rotation and complexity of pattern on the reversals of apparent movement in Lissajous figures. Am. J. Psychol. 58, 530-539.

Piaget, J (1969) The mechanisms of perception. G.N. Seagrin (Trans.) London; Routledge, Kegan and Paul.

Pikler, J. (1928) Grund und Figur dei schwacher Beleuchtung. Zsch. f. Psychol. 106, 316-326.

Porter, E.L.H. (1938) Factors in the fluctuation of fifteen ambiguous phenomena. Psychol. Rec. 2, 231-253.

Porterfield, W. (1759) A treatise on the eye,II. Edinburgh.

Poulton, E.C. and Gregory, R.L. (1952) Blinking during visual tracking. Q. Jl exp. Psychol. 4, 57-65.

Price, J.R. (1967a) Perspective duration of a plane reversible figure. Pschon. Sci. 9 (12), 623-624.

Price, J.R. (1967b) Two components of reversal rate for a rotating skeletal cube: 'conditioned satiation'. Aust. J. Psychol. 19, 261-270.

Price, J.R. (1969a) Effect of extended observation on reversible perspective duration. Psychon. Sci. 16 (2), 75-76.

Price, J.R. (1969b) Studies of reversible perspective: a methodological review. Behav. Res. Meth. Instru. 1 (13), 102-106.

Price, J.R. (1971) Satiation and confusion: a reply to Sadler and Mefferd. Percept. mot. Skills 33, 703-777.

Pritchard, R.M. (1958) Visual illusions viewed as stabilised retinal images. Q. Jl exp. Psychol. 10, 77-81.

Pritchard, R.M. (1961) Stabilised images on the retina. Scient. Am. 204, 72-78.

Pritchard, R.M., Heron, W., and Hebb, D.O. (1960) Visual perception approached by the method of stabilised images. Can. J. Psychol. 14, 67-77.

Ramamurthi, P.V. and Parameswaran, E.G. (1964) A study of figure reversals in the old and the young. J. Psychol. Res. 8, 16-18.

Rashbass, C. (1960) New method for recording eye movements. J. Opt Soc. Am. 50, 642.

Ratliff, F. (1958) Stationary retinal images requiring no attachments to the eye. J. Opt. Soc. Am. 48, 274-275.

Ratliff, F. and Riggs, A. (1950) Involuntary motions of the eye during monocular fixation. J. exp. Psychol. 40(6) 687-701.

Restle, F. (1975) Learning: animal behaviour and human cognition. New York; McGraw-Hill.

Richards, W. and Steinbach, M.J. (1972) Impaired motion detection preceeding smooth eye movements. Vision Res. 12, 353-356.

Richter, H.R. (1956) Principles de la photo-electronystagmographie. Rev. Neurol. 94, 138.

Riggs, L.A. (1972) 'Vision'. In J.W. King and L.A. Riggs (Eds.) Woodworth and Schlosberg's experimental psychology. London; Methuen.

Riggs, L.A. and Ratliff, F. (1951) Visual acuity and the normal tremor of the eyes. Science,N.Y. 114, 17-18.

Robinson, D.A. (1963) A method of measuring eye movement using a scleral search coil in a magnetic field. IEEE

Trans. Biomed. Electron. BME-10, 137-145.

Robinson, D.A. (1964) The mechanisms of human saccadic eye movements. J. Physiol., Lond. 174, 245-264.

Robinson, D.A. (1965) The mechanics of human smooth pursuit eye movements. J. Phsiol., Lond. 180, 569-591.

Robinson, J.O. (1972) The psychology of visual illusion. London; Hutchinson.

Robinson, J.O. and Wilson, J.A. (1973) The impossible colonnade and other variations of a well-known figure. Br. J. Psychol. 64, 363-365.

Rock, I. (1975) An introduction to perception. New York; Macmillan.

Rock, I. and Fleck, F.S. (1950) A re-examination of the effect of monetary reward and punishment on figure-ground perception. J. exp. Psychol. 40 (6), 766-776.

Rock, I. and Kremen, I. (1957) A re-examination of Rubin's figural after-effect. J. exp. Psychol. 53 (1), 23-30.

Rubin, E. (1915) Synsoplevede Figurer. Copenhagen; Gyldendalske Boghandel.

Rubin, E. (1921) Visuell wahrgenommene Figuren: studien in psychologische analyse. Copenhagen; Gyldendalske Boghandel.

Russo, J.E. (1975) The limbus reflection method for measuring eye position. Behav. Res. Meth. Instru. 7 (2), 205-208.

Sadler, T.G. and Mefferd, R.B. Jr. (1970) Fluctuations of perceptual organisation and orientation: stochastic (random) or steady state (satiation). Percept. mot.

Skills 31, 739-749.

Sadler, T.G. and Mefferd, R.B.Jr. (1971) Data requirements for satiation theories: a rejoinder to Price. Percept. mot. Skills 33, 999-1005.

Sakano, N. (1963) The role of eye movements in various forms of perception. Psychol. Kyata 6, 215-227.

Salapatek, P., Haith, M.M., Maurer, D., and Kessen, W. (1972) Error in the corneal reflection technique: a note on Slater and Findlay. J. exp. child Psychol. 14, 493-497.

Salapatek, P. and Kessen, W. (1966) Visual scanning of triangles by the human newborn. J. exp. child Psychol. 3, 155-167.

Sanders, A.F. (1970) Some aspects of the selective process in the functional visual field. Ergonomics 13, 101-117.

Sanders, J.L. (1977) The relationship of dogmatism to the nonrecognition of perceptual ambiguity. J. Psychol. 95, 179-183.

Santos, J.F., Farrów, B.F., and Solley, C.M. (1962) Exposure frequency and the perception of a reversible perspective. Percept. mot. Skills 14, 199-209.

Santos, J.F. and Garvin, E.A. (1962) A further examination of the Schafer-Murphy effect. Am. J. Psychol. 75, 259-264.

Saraga, E. and Shallice, T. (1973) Parallel processing of the attributes of single stimuli. Percept. Psychophys. 13 (2), 261-270.

Saslow, M.G. (1967) Latency for saccadic eye movement. J. Opt. Soc. Am. 57, 1030-1033.

Schafer, R. and Murphy, G. (1943) The role of autism in a visual figure-ground relationship. J. exp. Psychol. 32(4) 335-343.

Schmidt, M.J., Fulgham, D.D., and Brown, D.R. (1971) Stabilised images: the search for pattern elements. Percept. Psychophys. 10 (4b), 295-299.

Schott, E. (1922) Uber die Registrierung des Nystagmus und anderer Augenbewegungen vermittels des Seitengalvenometers. Deusches Arch. f. Klinische Med. 140, 79-90.

Schuster, D.H. (1964) A new ambiguous figure: a three stick clevis. Am. J. Psychol. 77, 673.

Selfridge, O.G. (1959) 'Pandemonium: a paradigm for learning'. In The mechanisation of the thought processes. London, H.M. Stationary Office.

Shackel, B. (1967)'Eye movement recording by electro-oculography'. In P.H. Venables and I. Martion (Eds.) A manual of psychophysiological methods. Amsterdam; North Holland.

Sheena, D. (1973) Two digital techniques for eye position measurement. Med. Instru. 7, 78.

Shopland, C. and Gregory, R.L. (1964) The effect of touch on a visually ambiguous three-dimensional figure. Q. Jl exp. Psychol. 16, 66-70.

Simon, H.A. (1967) An information-processing explanation of some perceptual phenomena. Br. J. Psychol. 58, 1-12.

Sinsteden, W.J. (1860) Über ein neues pseudoskopisches Bewegungsphänomen. Ann. Phys. Chem. 187, 336-339.

Sisson, E.D. (1935) Eye-movements and the Schröder stair-figure. Am. J. Psychol. 47, 309-311.

Slater, A.M. (1974) Visual behaviour in the newborn baby. Unpublished Ph.D. Thesis. Durham, Durham Univ.

Slater, A.M. and Findlay, J.M. (1972a) The measurement of fixation position in the newborn baby. J. exp. child Psychol. 14, 349-364.

Slater, A.M. and Findlay, J.M. (1972b) The corneal reflection technique: a reply to Salapatek, Haith, Maurer, and Kessen. J. exp. child Psychol. 14, 497-499.

Slater, A.M., and Findlay, J.M. (1975a) Binocular fixation in the newborn baby. J. exp. child Psychol. 20, 248-273.

Slater, A.M. and Findlay, J.M. (1975b) The corneal reflection technique and the visual preference method: sources of error. J. exp. child Psychol. 20, 240-247.

Slaughter, J.W. (1900) The fluctuations of attention and some of their psychological relations. Am. J. Psychol. 12, 313-334.

Sliney, D.H. and Freasier, B.C. (1973) Evaluation of optical radiation hazards. App. Optics 12 (1), 1-25.

Smith, D.E.P. and Hochberg, J.E. (1954) The effect of 'punishment' (electric shock) on figure-ground perception. J. Psychol. 38, 83-87.

Smith, D.E.P. and Raygor, A.L. (1956) Verbal satiation and personality. J. abnorm. soc. Psychol. 52, 323-326.

Solley, C.M. and Engel, M. (1960) Perceptual autism in children: effects of reward, punishment, and neutral conditions upon perceptual learning. J. genet. Psychol. 97, 77-91.

Solley, C.M. and Long, J. (1958) Perceptual learning versus response set learning. Percept. mot. Skills 8, 235-240.

Solley, C.M. and Murphy, G. (1960) Development of the perceptual world. New York; Basic Books.

Solley, C.M. and Santos, J.F. (1958) Perceptual learning with partial verbal reinforcement. Percept. mot. Skills 8, 183-193.

Sperry, R.W., Miner, N., and Myers, R.E. (1955) Visual pattern perception following subpial slicing and tantalum wire implantations in the visual cortex. J. comp. Physiol. Psychol. 48, 50-58.

Spitz, H.H. (1971) Scanpaths and pattern recognition. Science, N.Y. 173, 753.

Spitz, H.H. and Blackman, L.S. (1959) A comparison of mental retardates and normals on visual figural after-effects and reversible figures. J. abnorm. soc. Psychol. 58, 105-110.

Spitz, H.H. and Lipman, R.S. (1962) Some factors affecting Necker cube reversal rate. Percept. mot. Skills 15, 611-625.

Spivack, G. and Levine, M. (1959) Spiral aftereffect and measures of satiation in brain-injured and normal subjects. J. Pers. 27, 211-227.

Stark, L., Vossius, G., and Young, L.R. (1962) Predictive control of eye tracking movements. IRE Trans. Hum. Fact. Electron. HFE-3, 52.

Steinman, R.M., Cunitz, R.J., Timberlake, G.T., and Herman, M. (1967) Voluntary control of microsaccades during maintained monocular fixation. Science, N.Y. 155, 1577-1579.

Steinman, R.M., Haddad, G.M.,Skavenski, A.A., and Wyman, D. (1973) Miniature eye movements. Science, N.Y. 181, 810-819.

Sutherland, N.S. (1973) 'Object recognition'. In E.C. Carterette and M.P. Friedman (Eds.) Handbook of perception. Vol.III. Biology of perceptual systems. New York; Academic Press.

Taylor, M.M. and Aldridge, K.D. (1974) Stochastic processes in reversing figure perception. Percept. Psychophys. 16 (1), 9-27.

Taylor, M.M. and Henning, G.B. (1963) Transformations of perception with prolonged observation. Can. J. Psychol. 17, 349-360.

Thetford, P. (1963) Influence of massing and spacing on Necker cube reversals. Percept. mot. Skills 16, 215-222.

Thomas, J.G. (1961) Subjective analysis of saccadic eye movements. Nature, Lond. 189, 842-843.

Tinbergen, N. (1951) The study of instinct. Oxford; Clarendon Press.

Titchener, E.B. (1899) A primer of psychology. New York; Macmillan.

Titchener, E.B. (1901) Experimental psychology. Vol.I. pt. II New York; Macmillan.

Torok, N., Guillemin, V., and Barnothy, J.M. (1951) Photoelectric nystagmography. Ann. Oto. Rhino. Laryn. 60, 917.

Treisman, A.M. (1969) Strategies and madels of selective attention. Psychol Rev. 76 (3), 282-299.

Treisman, A.M. and Riley, J.G. (1969) Is selective attention selective perception or selective response ? A further test. J. exp. Psychol. 79 (1), 27-34.

Treisman, A.M., Sykes, M., and Gelade, G. (1977) 'Selective attention and stimulus integration'. In S. Dornic (Ed.) Attention and Performance VI. New York; Lawrence Erlbaum.

Trevarthen, C. (1968) Two mechanisms of vision in primates. Psychol. Forsch. 31, 299-337.

Tuddenham, W.J. (1962) Visual search, image organisation, and reader error in roentgen diagnosis. Radiology, 78, 694-704.

Vaegen (1976) Two parameters measure apparent change during repetitive stimulation. Q. Jl exp. Psychol. 28, 583-589.

Vernon, M.D. (1965) The psychology of perception. London; Univ. London Press.

Vetter, R.J. (1965) Perception of ambiguous figure-ground patterns as a function of past experience. Percept. mot. Skills 20, 183-188.

Vickers, D. (1972a) A cyclic decision model of perceptual alternation. Perception 1, 31-48.

Vickers, D. (1972b) 'Decision processes in perceptual organisation'. In J.F. O'Callaghan (Ed.) Pictorial organisation and shape. Canberra; ACT.

Virsu, V. (1975) Determination of perspective reversals. Nature, Lond. 257, 786-787.

Vitz, P.C. and Todd, T.C. (1971) A model of the perception of simple geometric figures. Psychol.Rev. 78 (3), 207-228.

Volkmann, F.C, (1962) Vision during voluntary saccadic eye movement. J. Opt. Soc. Am. 52, 571-578.

Wade, N.J. (1974) Figural effects in afterimage fragmentation. Percept. Psychophys. 15 (1), 115-122.

Wade, N.J. (1978) Why do patterned afterimages fluctuate in visibility? Psychol. Bull. 85, 338-352.

Walker, P. (1975) Stochastic properties of binocular rivalry alternations. Percept. Psychophys. 18 (6), 467-473.

Walker-Smith, G., Gale, A.G., and Findlay, J.M. (1977) Eye movement strategies involved in face perception. Perception 6, 313-326.

Wallin, J.E.W. (1905) Optical illusions of reversible perspective: a volume of historical and experimental researches. New York: The Author.

Wallin, J.E.W. (1910) The duration of attention, reversible perspectives and the refractory phase of the reflex arc. J.Phil. Psychol. Sci. Meth. 7 (2), 33-38.

Walls, G.L. (1962) The evolutionary history of eye movements. Vision Res. 2, 69-80.

Washburn, M.F. and Gillette, A. (1932) Motor factors in voluntary control of cube perspective fluctuations and retinal rivalry fluctuations. Am. J. Psychol. 45, 315-319.

Washburn, M.F., Mallay, M., and Naylor, A. (1931) The influence of size of an outline cube on the fluctuations of its perspective. Am. J. Psychol. 43, 484-489.

Washburn, M.F., Reagan, C., and Thurston, E. (1934) The comparative controllability of the fluctuation of simple and complex ambiguous perspective figures. Am. J. Psychol. 46, 636-638.

Weber, R.B. and Daroff, R.B. (1971) The metrics of horizontal saccadic eye movements in normal humans. Vision Res. 11, 921-928.

Weigl, E. (1927) Zur psychologie der sogenannten Abstraktionsprocesse. Z. Psychol. 103

Wertheimer, M. (1923) Untersuchungen zur Lehre von der Gestalt,II. Psychol. Forsch. 4, 301-350.

Westheimer, G. (1971)'Discussion of the control of eye vergence movements', In P. Bach-y-rita, C.C. Collins, and J.E. Hyde (Eds.) The control of eye movements. New York, Academic Press.

Wheeless, L.L., Boynton, R.M., and Cohen, G.H. (1966) Eye movement responses to step and pulse-step stimuli. J. Opt. Soc. Am. 56, 956-960.

Whiteside, J.A. (1974) Eye movements of children,adults, and elderly persons during inspection of dot patterns. J.exp. child Psychol. 18, 313-332.

Wieland, B.A. and Mefferd, R.B.Jr. (1966) Effects of orientation, inclination, and length of diagonal on reversal rate of Necker cube. Percept. mot. Skills 23, 823-826.

Wieland, B.A. and Mefferd, R.B.Jr. (1967) Individual differences in Necker cube reversal rates and perspective dominance. Percept. mot. Skills 24, 923-930.

Wilkinson, H.P. (1975) Wide range eye and head movement monitor. Q. Jl exp. Psychol. 28, 123-124.

Wong, E. (1975) Visual and tactile perception reconsidered: from an empirical phenomenological perspective. J. Phenom. Psychol. 6 (10),75-87.

Wundt,W. (1912) Human and animal psychology.(2nd. Ed.) London; Allen.

Yacorzynski, G.K. (1966) Brain dynamism in perception of reversible figures. Gen. Psychol. Monogr. 74, 37-87.

Yacorzynski, G.K. and Davis, L. (1945) An experimental study of the functions of the frontal lobes in man. Pyschosom. Med. 7, 97-107.

Yarbus, A.L. (1967) Eye movements and vision. New York; Plenum Press.

Young, L.R. (1963) Measuring eye movements. Am. J. Med. Electron. 2, 300-307.

Young, L.R. (1970)'Recording eye position'. In M. Clynes and J.H. Milsum (Eds.) Biomedical engineering systems. New York; McGraw Hill.

Young, L.R. and Sheena, D. (1975a) Eye movement measurement techniques. Am. Psychol. 30, 315-330

Young, L.R. and Sheena, D. (1975b) Survey of eye movement recording methods. Behav. Res. Meth. Instru. 7 (5), 397-429.

Zimmer, A. (1913) Die ursachen der Inversionen mehredeutiger stereometrischer Kouturenzeichnungen. Z. Sinnesphysiol. 47, 106-158.

Zinchenko, V.P. (1966) Perception as action. Proc. Int. Congr. Psychol., Moscow 30, 64-73.

Zinchenko, V.P. and Vergiles, N. Yu. (1972) Formation of _visual images. Studies of stabilised retinal images._ B. Haigh (Trans.) New York; N.Y. Consultants Bureau.

Zuber, B.L. (1971) 'Control of vergence eye movements'. In P. Bach-y-rita, C.C. Collins, and J.E. Hyde (Eds.) _The control of eye movements_ New York; Academic Press.

Zuber, B.L. and Stark, L. (1966) Saccadic suppression: elevation of visual threshold associated with saccadic eye movements. _Exp. Neurol._ 16, 65-79.

Zuber, B.L., Stark, L., and Cook, G. (1965) Microsaccades and the velocity-amplitude relationship for saccadic eye movements. _Science, N.Y._ 150, 1459-1460.

Zusne, L. and Michels. K.M. (1964) Nonrepresentational shapes and eye movements. _Percept. mot. Skills_ 18, 11-20.