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THE DESIGN AND TESTING

OF A

PORTABLE EYE MOVEMENT CAMERA

A Dissertation Presented

By

ROBERT A. SASSEVILLE

Submitted to the Graduate School of the
University of Massachusetts in partial fulfillment
of the requirements for the degree of

DOCTOR OF EDUCATION

February 1977

Education

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ACKNOWLEDGEMENTS

To the many people who made this study possible, I wish to express my gratitude.

I wish to express my gratitude to Dr. David G. Coffing for serving as Chairman of my doctoral committee, and for his unrelenting encouragement and assistance during the study.

Special appreciation and indebtedness is expressed to Dr. Juan Caban for his guidance in completing the manuscript.

Appreciation is extended to Dr. Robert Glorioso for his helpful technical advice.

For their continued patience, understanding, and encouragement, I wish to express my deepest thanks to my wife Joan and our children Marilou, Richard, and Gregory.

Finally, a humble expression of gratitude to my Mother for her constant inspiration in completing the study.

ABSTRACT

The Design and Testing

of a

Portable Eye Movement Camera

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During the past century progressively more sophisticated devices have been built to observe and record eye movement patterns. Unfortunately, some of these devices have been so bulky and costly that their use has been confined to a few laboratories.

This study describes the design and testing of a new portable eye movement camera to observe and measure eye movement patterns. The present design is smaller and less costly than previous eye movement cameras. This research explores the design parameters of accuracy, operation, size and cost in an effort to develop a small portable eye movement instrument that could be adapted in testing eye movement patterns. Such an eye movement camera could find effective use in schools by facilitating the task of identifying, in typical educational settings, the most suitable visual instruction for individual students.

TABLE OF CONTENTS

CHAPTER Page

APPENDICES

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

OVERVIEW OF THE STUDY

Statement of the Problem

An important way of obtaining information of how a subject learns is through observing his eye movements. Eye movements can help educators understand student learning styles, which has implications for the design of audio-visual materials.

By observing eye movements and fixations, a researcher can determine where the subject is looking, how long he looks at a particular area, how long he looks at a particular object, and the types of movements he makes. Why is this information useful? Carpenter (1972) theorizes that there is a correlation between a person's thought patterns and the small muscle movements of the eye. This theory suggests that some types of eye movements may be indicators of the subjects' immediate response to visual stimulus. Yarbus who supports this view, said "People that think differently see differently." (Yarbus, 1971, p. 211)

Many instruments for measuring eye movements have been developed in the past decade. These instruments range from the very simple, and accurate corneal mounted mirror reflectors, to the more sophisticated digital print-out units for computer analysis of eye movements.

The purpose of this study was to explore, design and build a new eye movement recording instrument which is inexpensive and small enough to be easily transported and effectively used in schools. Such a device could be used to field test and analyze visual presentations and materials for effectiveness and appropriateness to individual learning styles. The new instrument should facilitate the task of identifying under typical educational setting, the most suitable visual modes of instruction.

From a search of instrumentation literature it is evident that the corneal reflection type is inherently simpler in design and quite accurate. One eye movement camera that uses the corneal reflection is the oculometer. The Honeywell Oculometer, (Merchant and Morrissette, 1973) uses an invisible infra-red light source for the corneal reflection and uses a television camera with sufficient sensitivity in the infra-red region to detect this highlight.

Another design using the corneal reflection method is the Mackworth Wide Angle Eye movement Camera. In the Mackworth instrument the corneal reflection is a superimposed image of the viewed scene. For example, the square which is found in the center of the iris of the eye in Figure 1, is the object the subject is looking at. This simple corneal reflection technique provides a direct interpretable record of eye movement patterns.

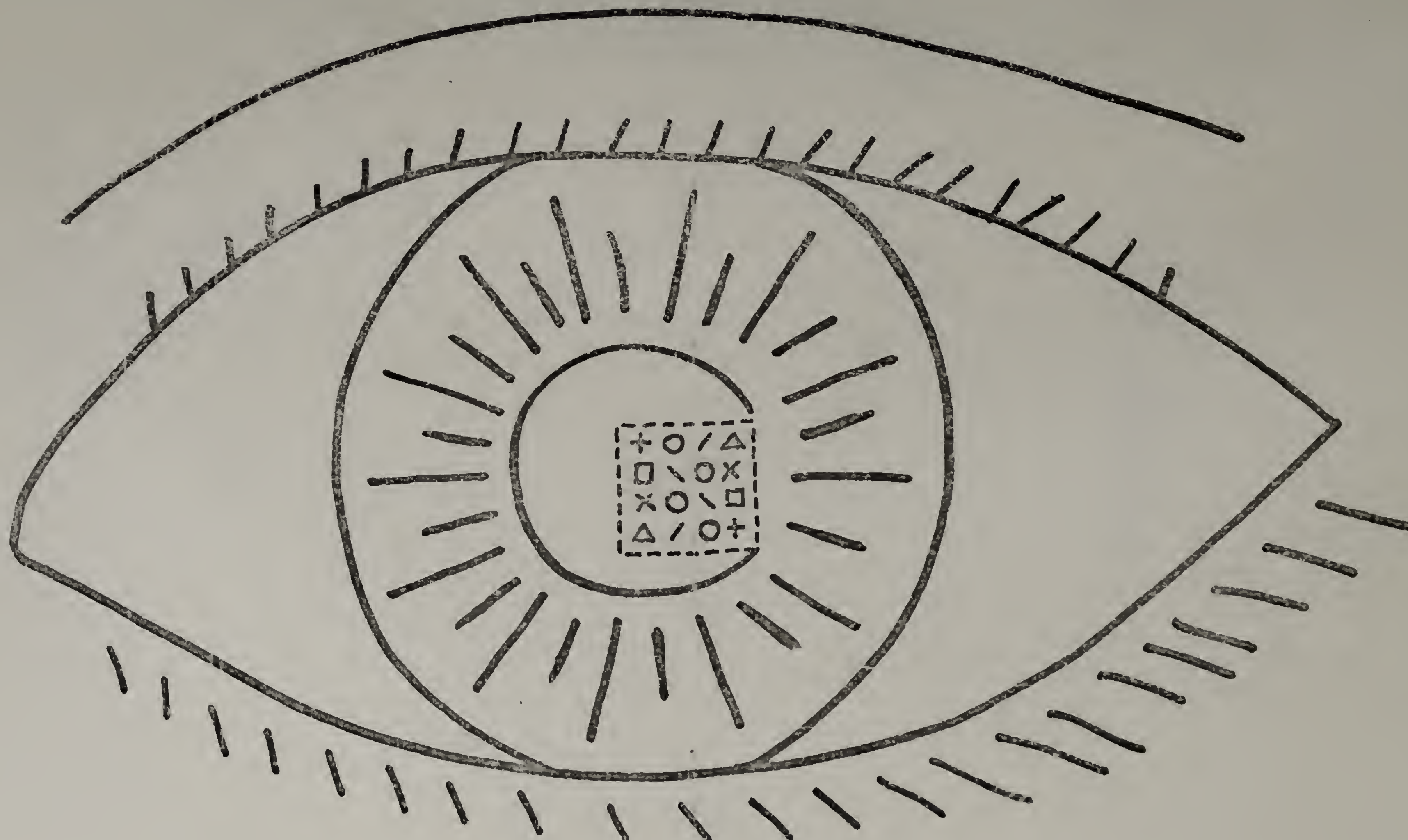


FIGURE 1 DRAWING FROM EYE PHOTOGRAPH TAKEN WITH MACKWORTH'S EYE MOVEMENT CAMERA

A review of eye movement research as a diagnostic tool for learning and methodologies previously used to collect eye movement data serves as the basis for developing the evaluation criteria applied to this new eye movement recording instrument.

Goals of the Study

This study explores the designing and building of a new and inexpensive eye movement recording instrument. In determining whether the proposed eye movement instrument could be considered an improvement over previous units the following factors were given paramount considerations: accuracy, operation, size and cost. These factors were utilized as study goals and were defined as follows:

1. Accuracy. The requirements are consistency of frame rate, repeatability of work cycle, clearness of image focus and discernability of eye fixation.

2. Operation. The requirements are simplicity, good picture quality, user comfort and machine quietness.

3. Size and Cost. The requirements are portability, sturdiness, pleasing aesthetic form, and reasonable cost.

Organization of the Study

This study, The Design and Testing of a Portable Eye Movement Camera, has been organized into four chapters:

Chapter I: Overview of the Study - Statement of problem; Goals of the Study; Organization of Study; Definition of terms.

Chapter II: Review of the Literature - Eye Physiology; Eye movement and learning; Eye movement technology: Techniques and instrumentation.

Chapter III: Method and Results - Design of instrumentation; and Evaluation.

Chapter IV: Discussion and Conclusion.

Definition of Terms

Eye movement: The voluntary and involuntary movement of the eyes.

Corneal reflection: The principle by which light is reflected from the cornea of the eye. It is used to study the position of the eye in reference to the visual stimulus it is viewing.

Eye movement technology: The use of instrumentation and technique that utilize the movement of the eyes as a source of data on a person's overt and covert reactions to visual stimuli.

<u>Individual differences</u>: Any characteristic of the individual that increases (or impairs) his probability for success in learning. (Cronbach and Snow, 1969, p. 7)

<u>Wide Angle photographs:</u> Method used to photograph the eye where an illuminated scene is used as the light source whose reflection is observed on the cornea. By photographing the eye at high magnification, the corneal curvature produces a superimposed image of the field being viewed, with the position being fixated lying directly in the center of the pupil.

<u>Oculometer</u>: A wide angle eye movement camera. A method that uses a single point corneal reflection, and determines how far it lies from the center of the pupil.

CHAPTER II

REVIEW OF THE LITERATURE

In this chapter the literature is reviewed and divided into three distinct areas. First, eye physiology is explained. Second, the relation between eye movements and learning is explored. Finally, previous instruments and techniques for measuring eye movements are described.

Eye Physiology

Eye Movements are easier to understand after consideration is given to the construction and functioning of the eye and the support structures. Mooney describes a relation between the eye and a photographic camera which services as useful analogy. (Mooney 1958)

The analogy required the following modifications to the nature of the film used: The camera, loaded with fine grain film of good color sensitivity, is mounted on a tripod that allows freedom of movement in both horizontal and vertical directions. The film is placed directly opposite the center of the lens. Surrounding this small area of high resolution and color sensitive film emulsion to the edge of the photographic material is a layer of increasingly course grain emulsion with drastically reduced color sensitivity. It follows then that to record the desired scene in sharp detail would require a succession of exposures such that a later composite picture could be constructed like a jig saw puzzle from the high resolution area of each of the exposures. This implies that a carefully directed sequence of camera directions is required in order to obtain a clear image of the target scene of interest.

This analogy implies that the eye must scan all aspects of the scene that are of interest to the observer if a detailed understanding of those aspects are part of the objectives of the observer. The use of a sequence of exposures assembled rather than a montage of images recorded on one photographic plate infers that an analysis of human intake of visual information requires data relative to the eye fixation. These eye movements are directed with reference to the visual field and this directed sequence is used to obtain coverage of the aspect of the visual field relevant to the objectives of the observer.

Support for this emphasis on a sequence of static recordings comes from work done by Mackworth and Mackworth (1958). They concluded that there was no useful visual information obtained during eye movement. Rather than information can only be obtained when the eye is relatively still, that is during the fixation between eye movements. In this sense, then, the use of the term eye movements when applied to the visual information obtained is a misnomer. Its use should be reserved to the analysis of how the subject proceeds to process items he considers important from the scene, i.e., the individual's order of interest merged with the individual's style of processing under the immediate task conditions under analysis.

Thus, eye movement refers to the sequencing of information intake, and eye fixation refers to what aspects of the scene are informationally important to the observer.

This analogy emphasizes the importance of considering the differences between central and peripheral regions of visual information intake. If sharp information is provided by a fixation, the peripheral or surrounding less sharp details from the visual scene should provide useful cues to directing the next eye movement to a fixation which will give sharp detail on the next feature to be considered.

With the above analogy in mind, the parts and the support systems of the eye require an examination and therefore are dealt with in the next section.

Parts of the Eye

The eye is made up of several parts: the sclera, the cornea, the lens, the aqueous humor, the vitreous humor, and the retina. (See Figure 2) Some of these parts are sub-divided. The parts will be described in order.

The Sclera is a tough membrane that forms the outer wall of the eye and is continuous with a transparent membrane, the cornea. The sclera functions to maintain the shape and the integrity of the eye as a container of fluids.

The Cornea is a transparent membrane that maintains the container qualities of the sclera while allowing light to pass through it and the eye lens

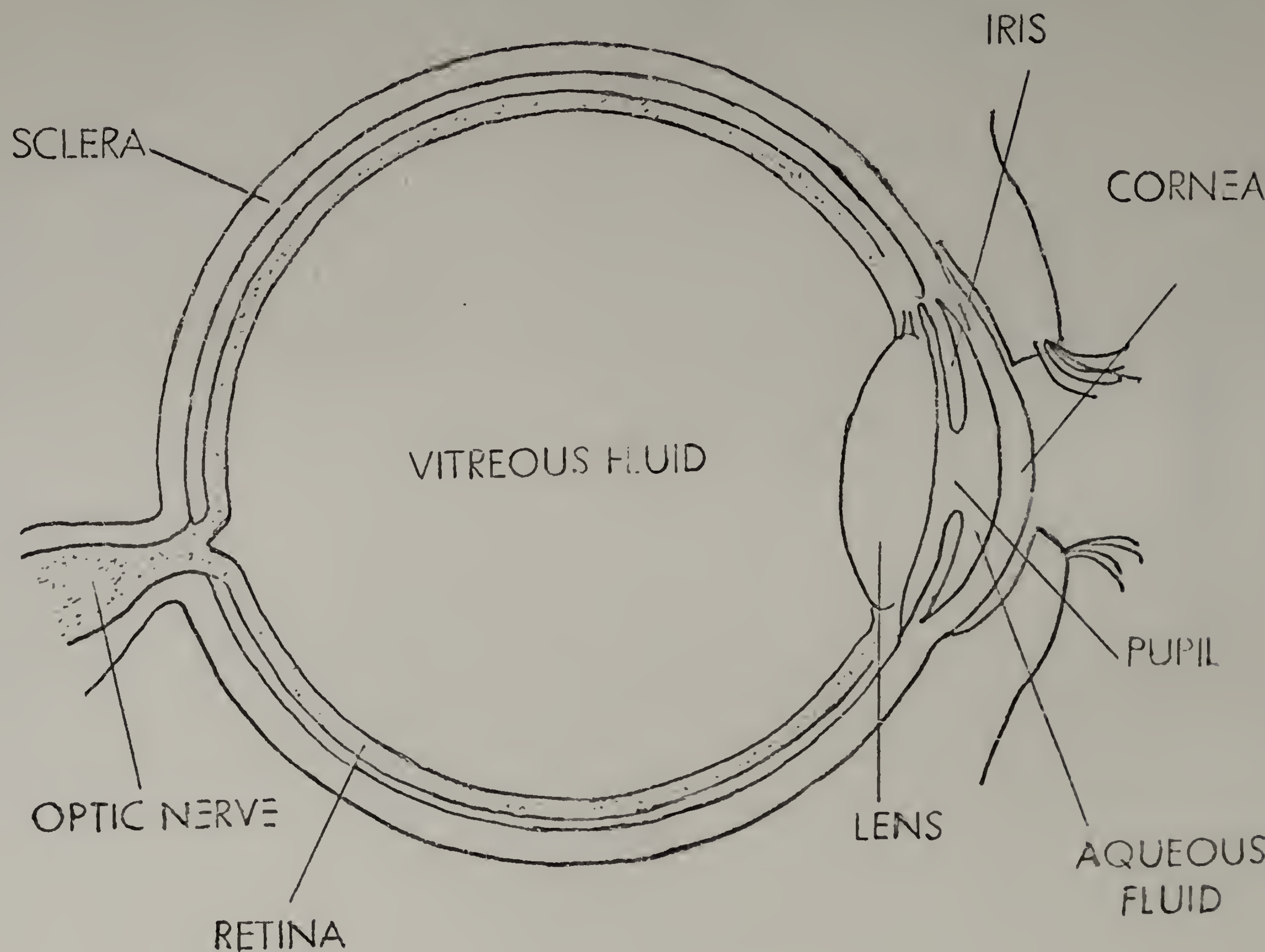


FIGURE 2 PARTS OF EYE

which lies immediately behind it on the outward surface of the eye. The iris lying between the cornea and the lens controls the amount of light passing through the lens. This light is focused on the foveal or color sensitive surface of the retina.

The Lens is a clear biconvex body that is pressure sensitive and that focuses incoming light onto the fovea.

The Aqueous Humor is a fluid filled space that lies between the cornea and the lenses.

The Vitreous Humor is the fluid filled space central to the eye surrounded by the retina and the lens.

The Retina makes up the inner wall of the eye, and as such, interfaces with the vitreous fluid except in the lens area. It is made up of different kinds of cells called cones and rods. The cones are color sensitive, bright light stimulated elements. The rods are low color sensitive elements, that function well under low light conditions. The retina has two sub areas of interest: the entry location of the optic nerve, the so-called "blind spot", and the fovea centralis, which is that part of the retina, approximately 0.4 mm in diameter, which is the retinal area with maximum resolution. (See Figure 3)

The following section contains a description of how the eye perceives an object.

EYE

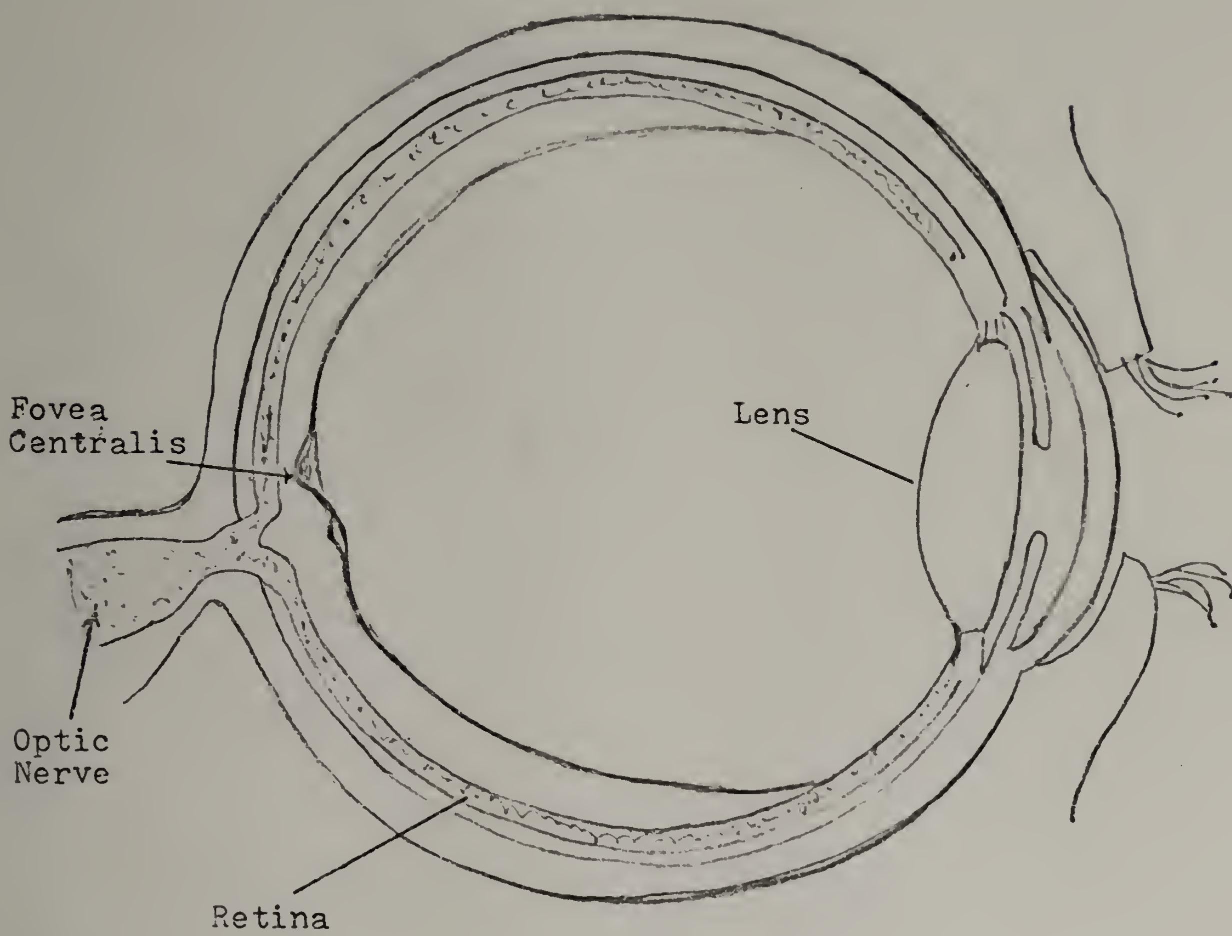


FIGURE 3 EYE STRUCTURE

Visual Perception

There are thought to be several stages in the visual perception process. First, the eye is pointed at the object. The visual display is focused on or near the foveal centralis so that this detailed information can be stored for processing. Second, the information obtained from one but probably many fixations on or near the fovea centralis is processed, assembled, assorted, etc. to prepare it for interpretation. Third, the on-going processed information is interpreted and used appropriate to the observer/environmental needs system. (Anderson 1958)

The above description of the process of gathering detailed visual information does not imply that peripheral vision cannot also provide useful information. However, only that material subjected to foveal centralis examination can be considered available for use where detailed information is required. That is, only the visual information directly looked at by the eye can be considered to have been examined in detail and therefore available for interpretation and use.

E. Llewellyn Thomas (1963) has indicated that the foveal centralis subtends approximately two degrees of angle. This creates a relatively narrow cone of sharp focus, thus supporting a requirement for rather directing the line of sight in reference to the detail that is desired from the visual field.

In practice, this cone would just subtend a penny at 15 inches.

Eye Movements

Movement of the eye is accomplished by three pairs of muscles attached to each eye. In each pair, the two muscles operate cooperatively in opposition to each other--when one contracts the other expands. (See Figure 4)

Inside each eye the ciliary muscles operate to alter the thickness of the lens according to the momentary distance from the visual target.

Most visual intake situations utilize information from both eyes, this requires an additional accommodation of line of sight of both eyes in order to accomplish convergence on the object or facet of interest. A further complication involves the probable head rotation associated with the looking process.

Considering observer introspection, Yarbus has stated, "Fixation of attention directed towards an element of a stationary object is accomplished by fixation of gaze. Subjectively, this fixation of gaze is perceived by the observer as fixation by stationary eyes." (Yarbus 1967, p. 127)

This concept of stationary eyes tends to ignore three minor eye movements: 1) small involuntary saccades; 2) slow irregular movements around the observational optical axes which are called drifts; 3) high frequency-low amplitude oscillatory axes movements called tremor.

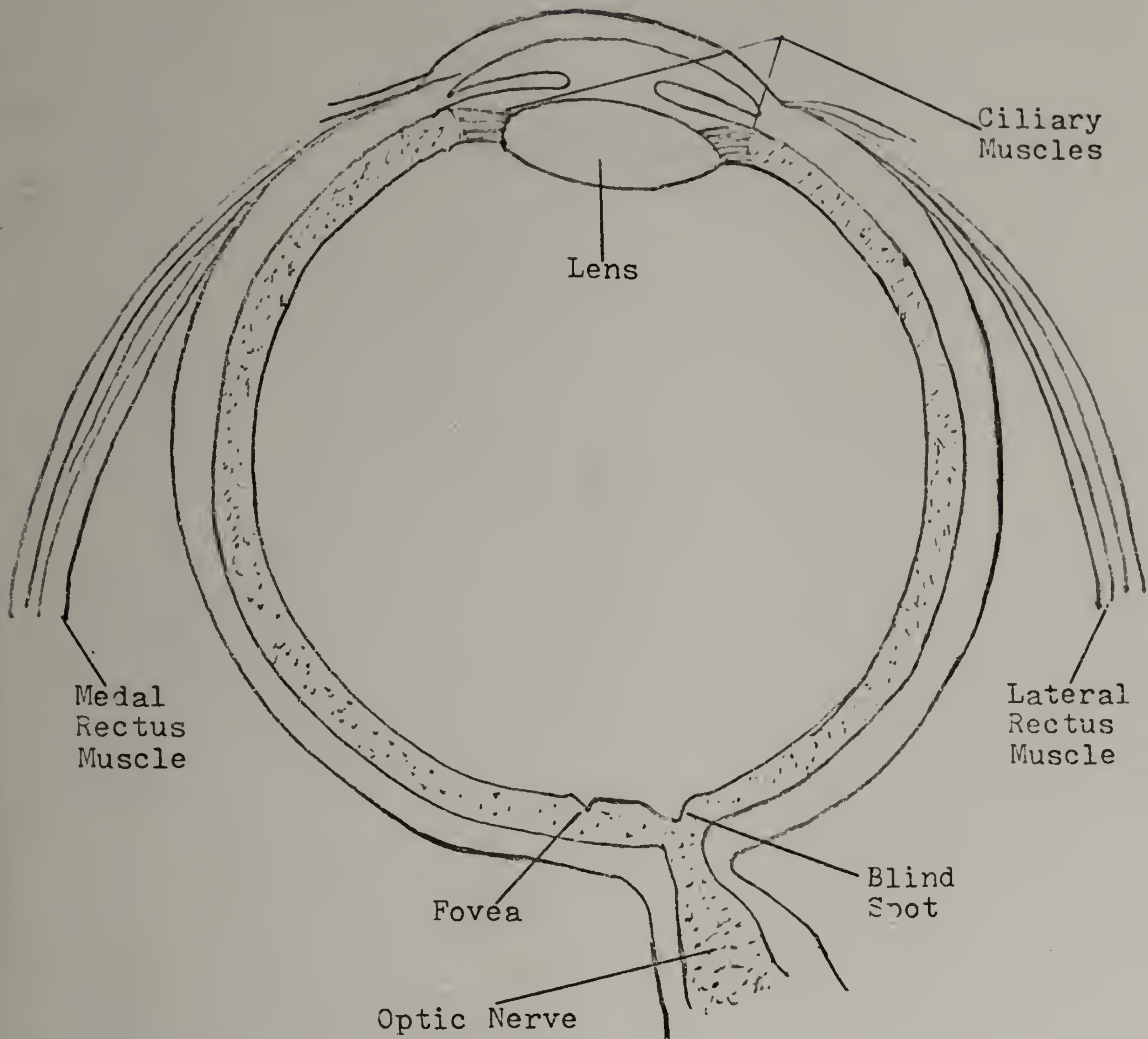


FIGURE 4 MUSCLES OF THE EYE

These minor activities seem to be required to maintain retinal stimulation. Yarbus has stated:

> In man under natural conditions the retinal image is never stationary relative to the retina, and if a strictly stationary and unchanging retinal image is created artificially, the eye ceases to see. In other words, within any object of perception remaining strictly stationary relative to the retina and unchanging in time, after about 1-3 seconds all visual contours disappear (the resolving power of the eye rapidly falls to zero). (Yarbus 1967, p. 103)

Yarbus further states that:

> Some readers may think that during perception of stationary objects the human eyes are able to perform smooth pursuing movements in addition to saccades. . . this view is incorrect. Although subjectively the tracking movements of the eyes seems smooth and uninterrupted, they are in fact, composed of discreet stops (called fixations) and small saccades. (p. 104)

The concept of eye fixation must be modified to accommodate these minor eye movements and possible head movements in addition to the major eye directing saccades. Importance assigned to these several movements would of course depend upon the nature and level of the question under examination. Normally, head movements are controlled either physically, observationally, or statistically. The three minor movements mentioned above are assumed to be involuntary and unbiased by the condition of examination. Most analyses concern location and length of fixation and their sequence in reference to the field of view, the task, past experience, etc.

Intervals of movement between fixations are normally not involved in the measurement system due to the extremely rapid speed of movement, i.e., normal saccades move at 200-500 minutes of angle per second, thereby rendering measurement very difficult. (Thomas 1963)

Eye Movement and Learning

Some recent research at Stanford University and the University of Massachusettts has shown statistically significant relationships between some eye movement fixation patterns and the learning styles of some individual learners. (Coffing, 1971; Caban, 1972; Walker, 1973; Harris, 1975; Packard, 1975; Haas, 1975; and Davis, 1975) This research offers confirmation for the theory that the way a person uses his eyes may provide some clues as to that individual's information processing style relative to the particular learning situation the person is dealing with at that moment.

Yarbus offered further confirmation of this approach when he stated:

> The human eyes voluntarily and involuntarily fixate on those elements of an object which carry or may carry essential and useful information. The more information is contained in an element, the longer the eyes stay on it. The distribution of points of fixation on the object changes depending on the purposes of the observer; i.e., depending on the information which he must obtain from different parts of objects. The order and duration of fixations on elements of an object are determined by the thought process accompanying the analysis of the information obtained. Hence, people who think differently also to some extent, see differently. (Yarbus 1967, p. 211)

Thus, eye fixation pattern analysis may provide predictor information relative to individual responses to particular learning situations. If this approach finds further confirmation, then the eye movement preferences may become useful in the prediction of individual differences in learning.

Reading and Eye Movement

Eye movement related to the reading process has been under examination for more than one half century using different technical procedures to elicit eye behavior. This approach has been justified as having high fact validity. That is, the reader must move his eyes along the print in some coordinated, systematic way if the test is to be made ready for comprehension. Typically the reader moves his eyes left to right along a line of English language material according to his past reading experience, familiarity of the material, style of presentation, interest in the material, etc.

If eye movement behavior of an individual reflects his idiosyncratic processing style, then the potential usefulness of the procedure is supported.

Eye Movement and High Scholastic Performance

Anderson has concluded that "High performers (IQ) exhibit fewer fixations and regressions than low performers. . . high performers have a total duration of fixations and regressions lower than low performers." (Anderson 1958, pp. 262-270)

Another researcher, J. Enoch, has also presented supporting material: "Subjects of low achievement devote nearly twice as much time, 2.05 sec., to acquire one unit of subject matter, as do their superior competitors, who devote only 1.17 sec. to achieve a unit of the same type of subject matter." And in reference to individual difference, he has stated:

> Conditions which influence and determine the character of ocular patterns in learning situations are the intellectual capacity of the individual, the character of the observed field, the nature of the problem, the past experience of the learner, and the purpose of the learner of the time of observation. The ocular patterns show the materials presented. Organization in this sense of the term is no longer an abstract idea. It has meaning in terms of ocular performance which reveals the method and procedure employed by the learner in acquiring certain types of information; how he attacks the problem, how he organizes his data, and how he distributes his efforts. (Enoch 1960, p. 712)

Guba and Wolf have also supported the probable relationship between eye movement and success in school: "A sizable correlation between some of the eye movement indices of subjects in the pilot study and intelligence was measured by the California Test of Mental Maturity." (Guba and Wolf 1964, p. 3)

Perception and Cognitive Process

Travers (1966) and Broadbent (1958) in their perception model, (see Figure 5) state that perception goes through a process of selection. This selection operates to reduce or eliminate redundant information from being transmitted to the brain, and is accomplished by the individual's cognitive processing structure. Miller, Galanter and Pribram (1960), have offered an intake selection process theory that involves the construction and use of templates which are matched with this incoming material in order to assign it to novelty or redundant information categories. These perceived units of information are then compared to past experiences, ideas, and judgments so that an evaluation to store or act upon these units of information may be made.

Eye Movement Technology

Technique

The cause of overt eye movements have been of interest to man for many years. The application of a sophisticated study of eye movements did not occur until the advancement of technology in the nineteenth century. Methods to directly measure overt eye movements were developed in order to relate them to what was being viewed. The techniques to study eye movements are grouped into several categories:

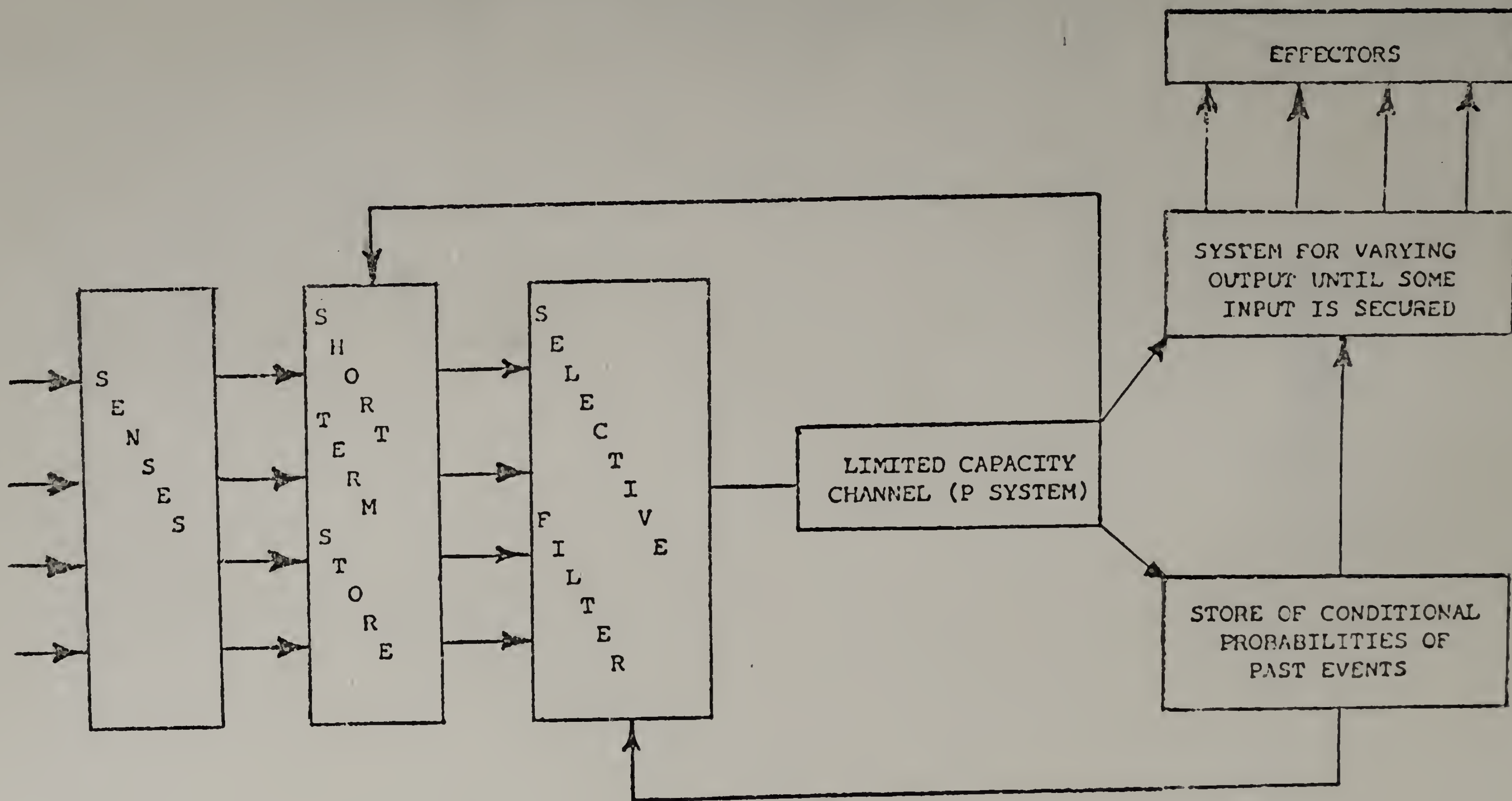


FIGURE 5 BROADBENT'S PERCEPTION MODEL

1. <u>The direct observation of an eye by an observer.</u>

The direct observation of eye movements, associated with the viewing of a scene, has proven to be inaccurate, due to the speed of acceleration of these movements. A method to permanently record these movements is essential in eye movement studies.

2. <u>The latent image observation.</u>

Herman Von Helholtz, in 1858 gave an explanation as to the nature of the causes of latent images. A latent image is defined as an image observable to the subject, which occurs only after the viewed stimulus has been removed from view. Latent images can be perceived by the observer for approximately 20 minutes. These images remain visible with the eye closed or open.

Yarbus has stated: "Since the after-image is strictly stationary to the retina, the <u>apparent</u> movement of this image on the screen corresponds directly to the movements of the eye. Knowing the distance between the eye and the screen, it is easy to determine the eye movements performed during fixation with rough accuracy." (Yarbus 1965, p. 211) Although the latent image technique proved helpful in early eye movement analysis, new tools to provide a permanent record of eye movements as to the degree and direction of movements were necessary for more accurate measurements.

3. <u>The mechanical eye attachments.</u>

E. B. A. Dellbarre, in 1898, form fitted cups of ivory, aluminum, rubber, and other materials to the cornea of the eye. Attached to these cups was a series of levers which activated a recording stylus when the eye was moved. The movements of the eye were recorded by the stylus as squiggle lines. This method of recording eye movements, though crude, was a more accurate method to directly analyze these movements as they viewed visual tasks. These experiments led to more sophisticated techniques of measuring eye movements by the attachment of elements to the sclera of the eye.

4. The reflection of a light beam from a mirror attached to the sclera of the eye.

In the technique of reflecting a light beam from the eye a cup with a mirror attached to it is placed on the sclera of the eye. This mirror reflects a beam of light directly onto a film where the eye movements are recorded.

Extensive eye movement experiments using suction cups and mirrors have been carried out by Yarbus (1965).

Another technique of attaching mirrors to eyes is by means of contact lenses as used by Ditchburn and Ginsborg (1952) and Riggs, Ratcliff, Cornsweet and Cornsweet (1953). Ganz and Wilson (1967), used contact lenses in their work with Rhesus Monkeys and found that the fluid between the eye and the contact lens, caused a lag in the lens movement as compared to the speed of the eye motion.

All of the methods employing attachments to the eye caused a pressure against the eye, besides causing a lack of sensitivity in recording. These attachments undoubtedly caused discomfort to the subject, thus reducing the validity of the test results.

5. <u>The pictures of eye movements</u>

After many years of recording eye movements by attaching mechanical elements directly to the surface of the eyes, new techniques were advanced to facilitate the process. One new recording technique was the use of photography and television to permanently record the activities of the eyes. This technique proved effective as a means of recording the direction and extent of eye movements.

In 1940, Brandt developed an eye recording camera to record both the vertical and horizontal motions of the eye. This camera photographed the reflection of light from the cornea of the eye. A correlation was made between the spot of light on the cornea and its location as recorded on a photographic film. In this manner the position of the reflected beam of light could be superimposed over a photograph of the visual scene being observed. This method of eye recording proved to measure eye positions with fair accuracy.

6. <u>The picture of the eye with regard to the exact position of the scene which is being foveally observed.</u>

This method, also called wide angle photography, is the process on which the present study is based. The eye movements, and the reflection of the scene being viewed is recorded on motion picture film. This technique of recording a scene as observed makes use of the reflection from the cornea of the eye. The center of the eye is used as a reference point to establish the area of the scene the subject is looking at. Figure 6, shows a diagram with a

URE REPRESENTATION OF A FILM FRAME PHOTO
FROM THE EYE MOVEMENT CAMERA

representation of a reflected display from the cornea of the eye. Brandt states, "The analysis of ocular performance by means of photography is thus a promising field of research in many respects." (Brandt 1940, p. 13)

Upon surveying eye movement studies, Brandt further states, "In every case, new information has been revealed leading to the general conclusion that eye movements have a functional relation to the central processes of the learner." (Brandt 1940, p. 13)

7. Pictures with superimposed corneal reflected light.

A recording process using a reflection of a spot of light from the cornea of the eye, which is superimposed on a picture of the viewed scene has been a method used to establish accuracy recording of the direction and the extent of eye movements. This technique normally referred to as the corneal reflection technique has proven to be the most practical and is the most widely used method for studying eye movements. From 1899 through the 1930's many corneal reflection cameras were built for educational testing.

It is to be noted that in this method, the amplitude of movement of the reflection is equal to one-half the actual displacement of the apex of the cornea, but always in the same direction. When this method is used in recording eye movements, the corneal slippage is of no real significance, and does not detract from the accuracy of eye movement recording.

Mackworth and Llewellyn, (1962) reported their development of the improved eye marker system; which made a recording of the scene, the eye movements and the eye fixations within a viewed scene. (See Figure 7) This system recorded the scene observed by the subject with a film or television camera. A spot of light is projected from a small electric bulb onto the cornea. The light spot is transmitted by a mirror, placed near the eye, and superimposed on a permanent recording of the viewed scene. The superimposed reflection from the cornea and the recorded scene being viewed is used as a reference to show where the subject is looking.

This eye movement technique has a recording accuracy of 0.1 degree, as well as being small and light enough to be adapted for use as a head mounted camera.

8. <u>The electro-sensing device.</u>

The position of the eye can be determined accurately by recording the potential difference between electrodes placed around the eye. Electrodes attached around the eyes of a subject can record the electric current generated by the movement of the eye or facial muscles.

This method of recording eye movements is called Electro-Oculography. It has certain advantages over all other recording methods, in that the subject's eyes are unencumbered and the head is relatively free. The method is usable for eye movements up to ± 70 degrees.

The electrical signals generated from the Electro-Graphic equipment may be amplified to be fed into a computer to project on a screen for use in determining the position of foveal focus.

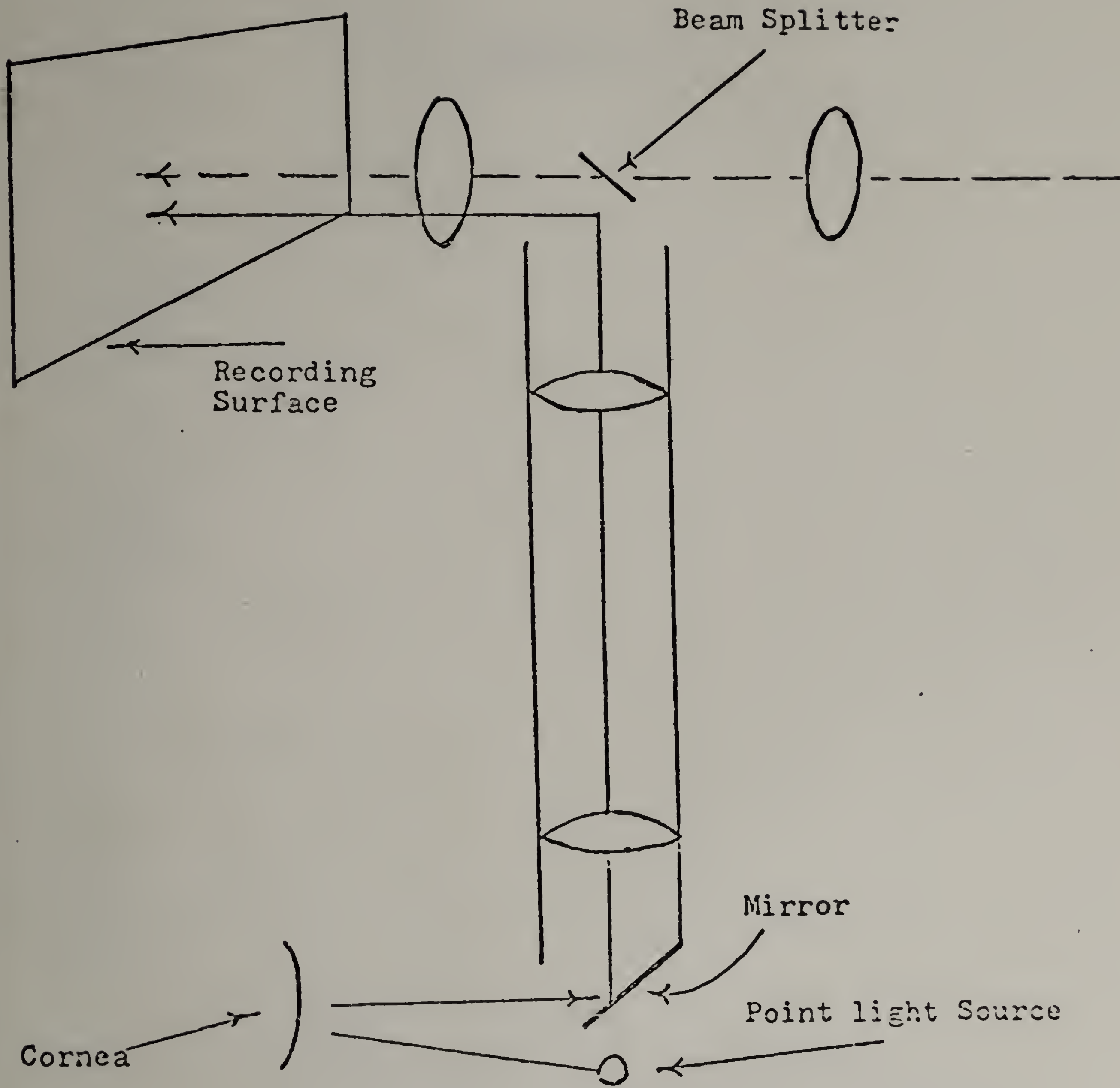


FIGURE 7 MACKWORTH AND THOMAS EYE MARKER SYSTEM

Instrumentation

The design of the present Portable Eye Movement Camera was an outgrowth of previous eye movement camera designs by Coffing (1971), Caban (1972), and Davis (1975). These instruments were modifications of the Mackworth Wide Angle Camera.

The Mackworth Wide Angle Camera.

Mackworth's eye movement camera records the reflection off the cornea of the subjects eye of the display being viewed by the subject.

A commercial version of the Mackworth Wide Angle Recorder is available from the Polymetric Company, New Jersey. (see Figure 8) The apparatus consists of a housing, with a binocular viewing aperture on one side. Opposite the viewing aperture is a stage where stimulus material may be presented. This stage may be fitted with a rear projection screen, for use with an external slide or motion picture projector. Within the apparatus are a light source to illuminate the eye, and an optical system that photographically records the reflection of the stimulus material from the corneal surface of the eye such that the particular point of the screen being viewed would be superimposed over the center of the pupil opening. This device is equipped with an electric-drive 16mm reflex motion picture camera that may be set to slow rates of image exposure such as four or five frames per second.

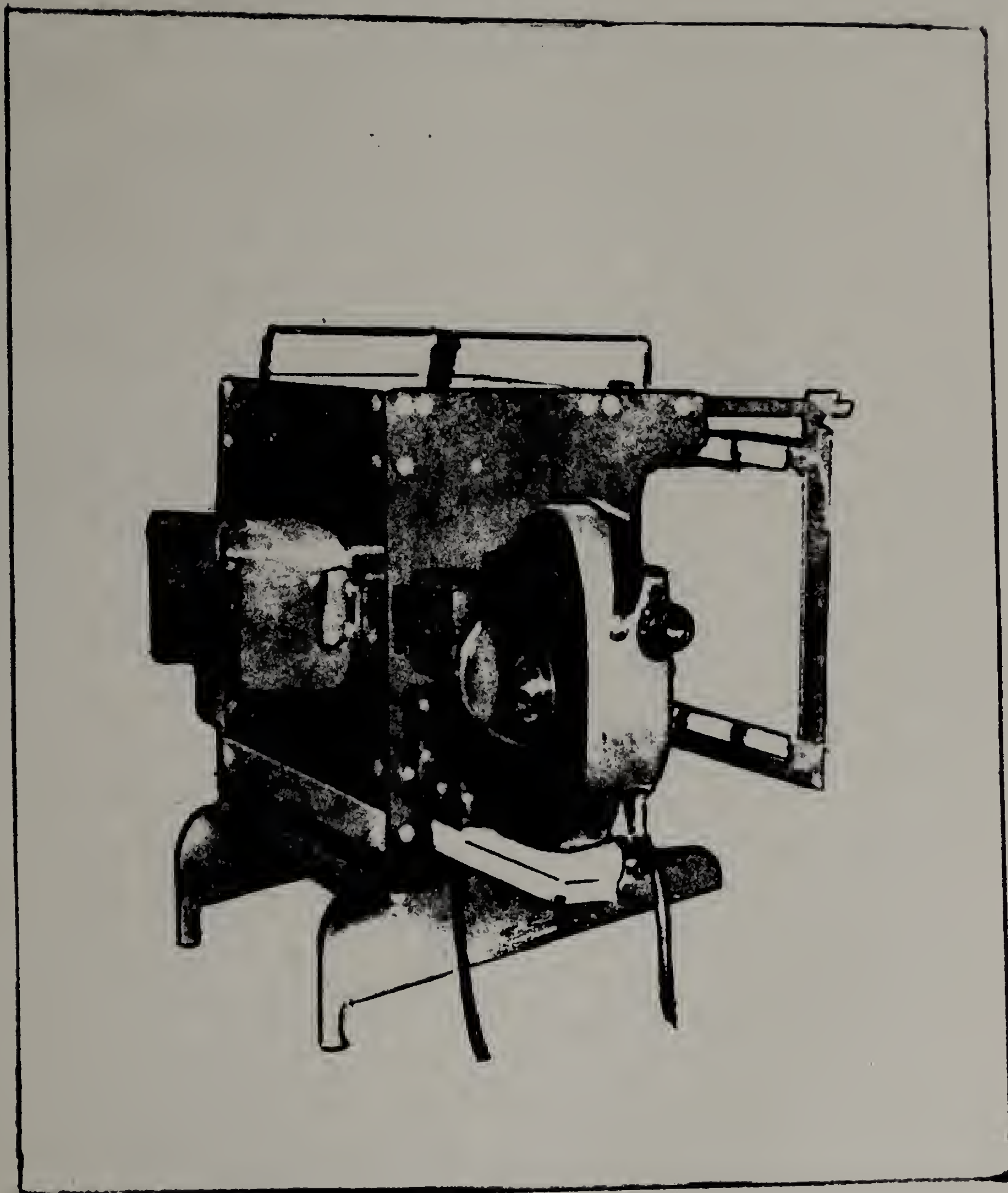


FIGURE 8 MACKWORTH WIDE ANGLE RECORDING CAMERA

Specifications

Image size	8 x 8 inches
Field of view, angular	40 degrees maximum
Viewing distances	14 inches to 10 inches variable
Recording accuracy	plus or minus 2.5 degrees
Recording apparatus	16mm reflex motion picture camera with electric drive
Size (without camera attachment)	24 inches wide x 18 inches long x 16 inches high
Weight	46 lbs.

Coffing Eye Movement Camera.

This instrument records eye movements using a television camera and videotape recorder. These videotape recordings were later filmed from a television display using a Arroflex 16mm motion picture camera and analyzed. Visual stimuli was presented using a Kodak projector via a front surfaced mirror to a rear projection screen. An example of this camera is presented in Figure 9. The eyes were illuminated by two small spot lights placed on each side of the two-way mirror.

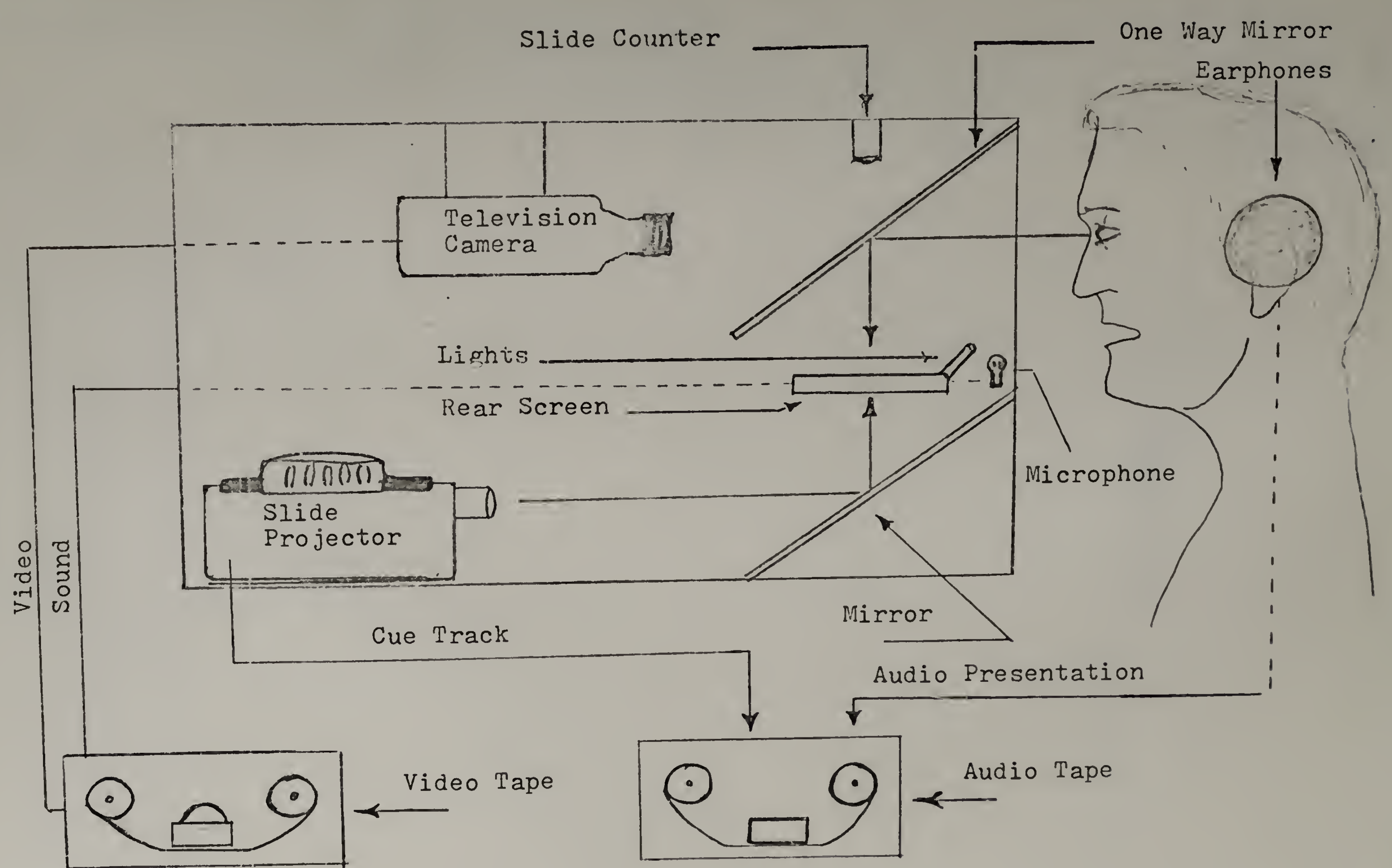


FIGURE 9 COFFING EYE MOVEMENT CAMERA

Specifications

Image size	8 x 10 inches
Field of view, angular	35 degrees maximum
Viewing distance	20 inches
Recording accuracy	plus or minus 2.5 degrees
Recording apparatus	television camera and videotape
Size (without camera attachment)	14.5 inches wide x 36 inches long x 26 inches high
Weight	60 lbs.

Caban Eye Movement Camera.

In this eye movement instrument, the visual stimulus was projected with a Kodak-800 Carousel Projector by way of a front surfaced mirror on to a high gain image reflection screen.

The stimulus was viewed by the subject through a 30/70 two-way mirror. A Lecina Super-8 Motion Picture Camera filmed the eye by way of the two-way mirror reflection. The camera was activated by a five contact per second hysteresis synchronous camera triggering unit. This camera required continuous aiming and focusing.

The eyes were illuminted by two forty watt light units with heat filters to prevent heat discomfort to the subject. As shown in Figure 10 the specifications of the Caban instrument are:

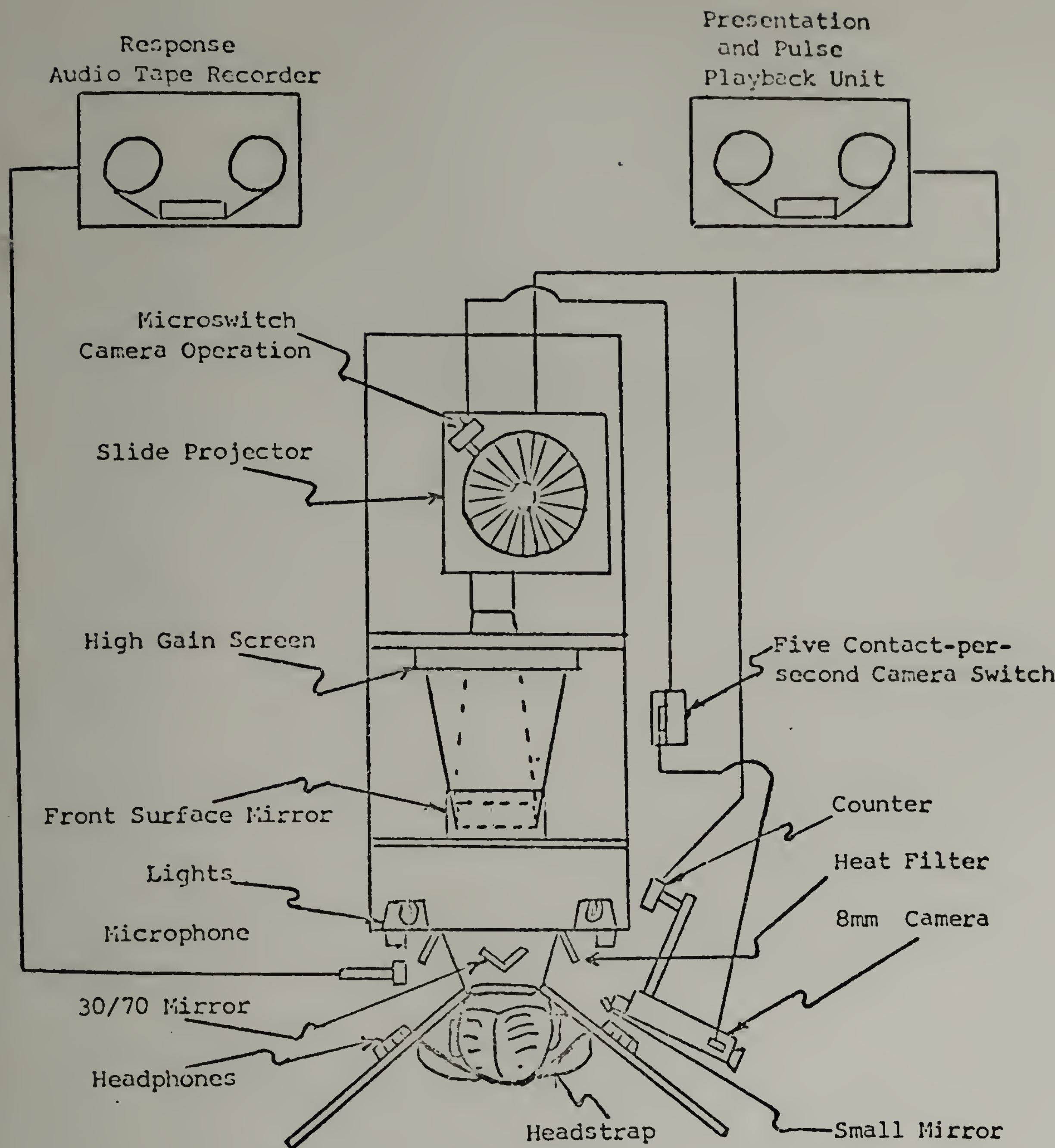


FIGURE 10 CABAN EYE MOVEMENT CAMERA

Specifications

Image size	8 x 10 inches
Field of view, angular	35 degrees maximum
Viewing distance	20 inches
Recording accuracy	plus or minus 2.5 degrees
Size (without camera attachment)	14.5 inches wide x 36 inches long x 26 inches high
Weight	60 lbs.

Davis Eye Movement Camera.

This instrument records eye movements using a Konica Super-8 motion picture camera. The camera is operated by an external synchronous motor connected to the camera by a gear reduction unit. The subject views the image through a 30/70 two-way mirror which was also used to direct the eye reflection to the camera. Two flourescent lamps softly illuminate the eyes through the transluscent eye-viewing unit.

The instrument eliminates focusing and aiming problems by using a fixed focused pre-positioned camera. Full frame photography of the subjects' eyes is possible by utilizing extreme close-up lenses, while keeping the camera stationary, as shown in figure 11. The specifications of the Davis camera are:

Eye Movement Recording Apparatus

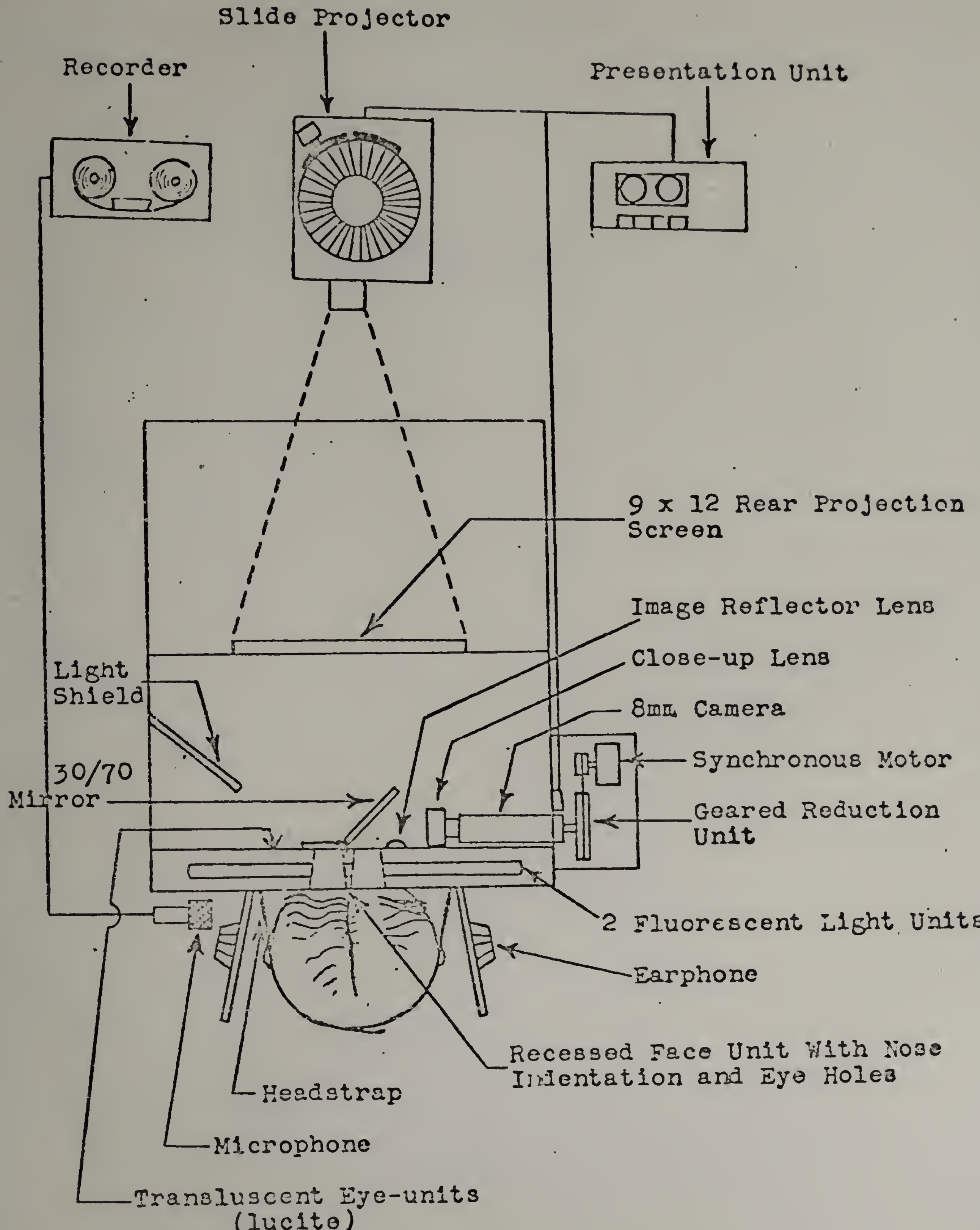


FIGURE 11· DAVIS EYE MOVEMENT CAMERA

Specifications

Image size	9 x 12 inches
Field of view, angular	40 degrees maximum
Viewing distance	14 inches
Recording accuracy	plus or minus 2.5 degrees
Recording apparatus	Konica Super-8 camera with external electric drive
Size (without camera attachments)	20 inches wide x 26 inches long x 24 inches high
Weight	40 lbs.

CHAPTER III

METHOD AND RESULTS

In this chapter the design considerations and construction of the portable eye movement camera are described in detail. (See Appendix I for exact measurements). Concurrently, the evaluation of the finished camera is discussed in terms of the goals of this study.

Design of Instrumentation

There are three major design considerations in the construction of the present instrumentation: 1) accuracy, 2) operation, and 3) size and cost. The equipment is housed in a fiberglass enclosure. The recording unit consists of a modified super-8 camera used to photograph the eye at five frames per second via a two-way mirror in the view channel. Illumination from an eight inch fluorescent lamp is supplied to each eye through a plexiglass frame. Stimulus images for subject viewing are projected on a rear screen. Since many presentations are visuals accompanied by audio, this new design eye movement instrument incorporates two speakers for accompanying audio presentations.

Housing Unit

The main housing has a smooth color-blended polyglass finish, which is easily cleaned and is free from electric shock hazard. Decorative inserts of wood grained formica are used around the eye-illuminator, and also in the film camera canopy. Parts of the main housing unit handle and speaker enclosures are made of polished aluminum and steel.

Construction of the eye movement camera began with the main housing. A housing unit with the following specifications was constructed. The new camera design is shown in figures 12-13.

Length	23 inches
Width	12 inches
Height	10 inches
Weight	15 pounds

The housing unit, although compact, is large enough to hold the following components:

1. 50/50 two-way mirror
2. Eye-illuminator
3. Polacoat rear-projection screen
4. Microphone
5. Speakers
6. Stimulus reflector
7. Super-8 camera

The housing unit is made of one-fourth inch plywood sections that are glued and nailed at all contact points. The scale layout of the new design eye movement camera can be seen in Appendix I. The top and bottom contours of

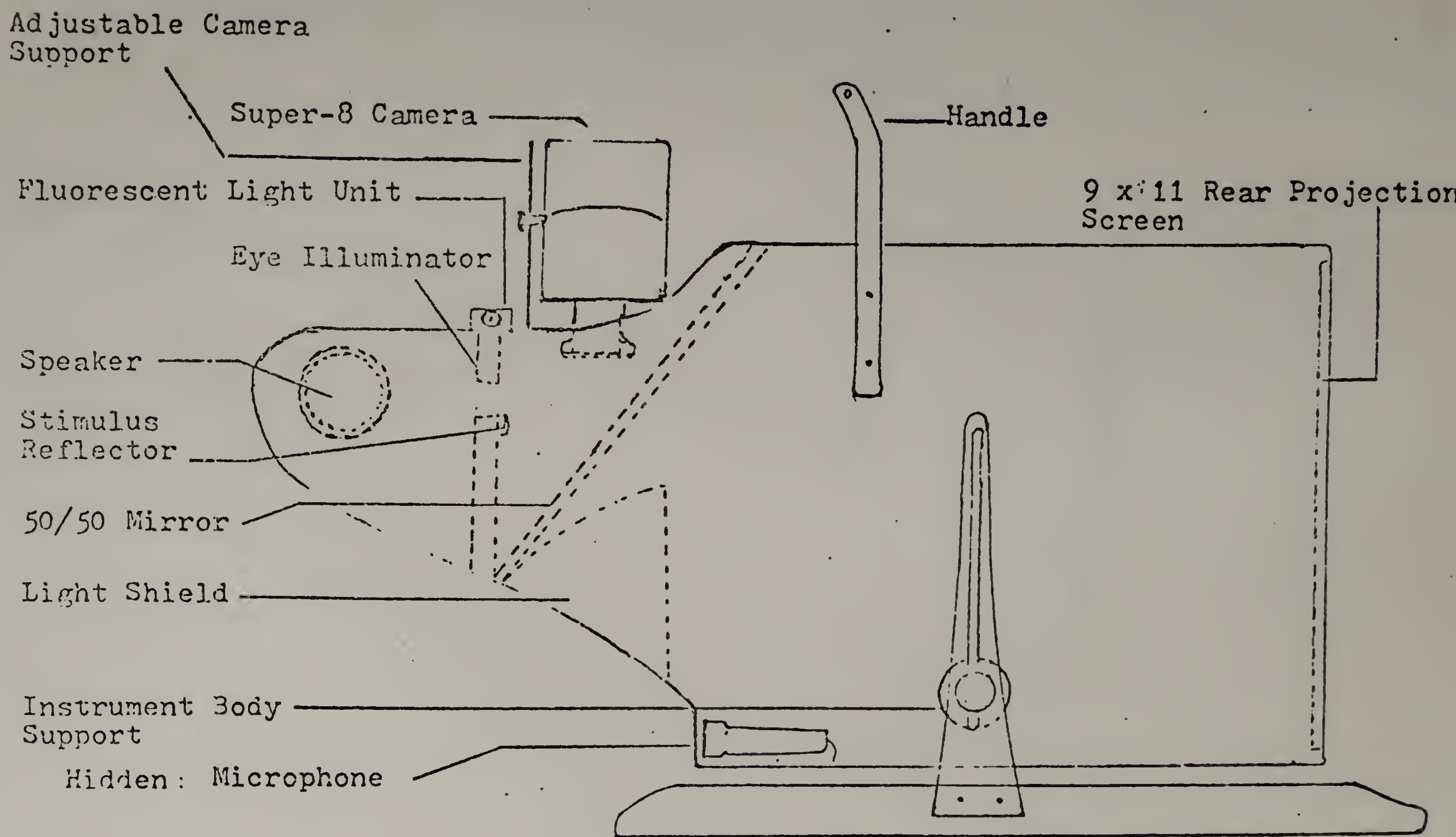


FIGURE 12 DIAGRAM OF NEW DESIGN EYE MOVEMENT CAMERA

(Side View)

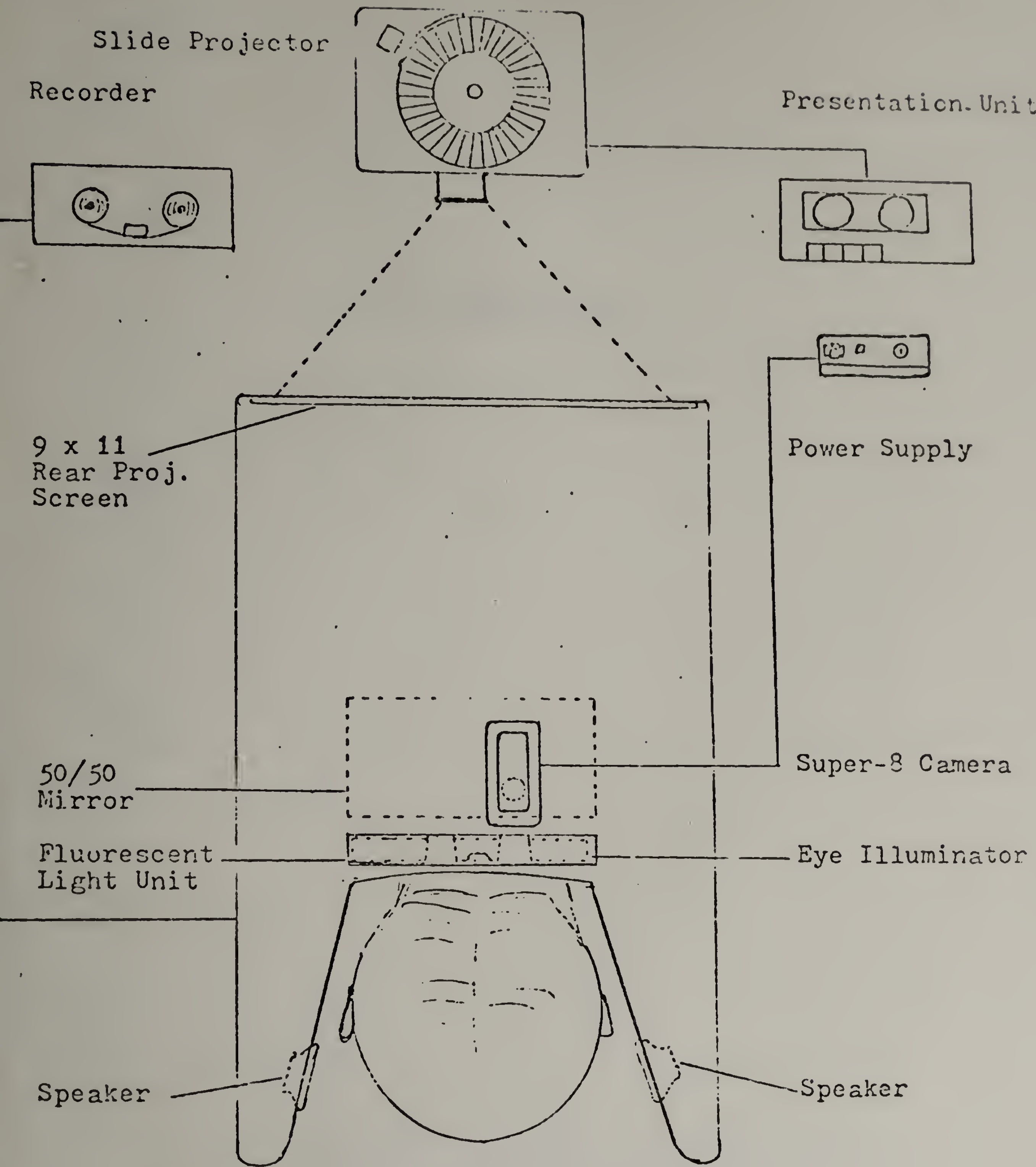


FIGURE 13 DIAGRAM OF NEW DESIGN EYE MOVEMENT CAMERA
(Top View)

the housing are formed with thin layers of aluminum and fiber glass cloth. It is covered with a single layer of poly-glass mesh, which is coated with two layers of poly-glass resin. The external finish of the housing is sprayed with three coats of Dupont Automotive Enamel.

The adjustable leg supports which were added to the housing unit are used to adjust the instrument to the desired viewing height, are detachable for storage in the camera housing unit.

Both the handle and leg supports have been constructed from machined one-eighth inch metal stock for sturdiness.

The construction of the instrument housing unit from non-conducting wood and fiber glass materials increases the user safety from electrical grounding from the power supply and electrical instrumentation and in the presentation and recording equipment of the eye movement camera.

Eye Movement Recorder

Eye movement images and visual stimuli are recorded by a wide-angle Kodak Super-8 camera from the reflections on a two-way mirror. The camera is mounted vertically on the instrument housing, directly over the right eye. (See Figure 13, p. 43)

Recordings of the eye are filmed at 5 frames per second, using a 160 ASA film speed to produce clear bright eye photographs in a low light field.

Camera Selection.

A Super-8 XL-33 Movie Camera was tested and selected to photograph the visual stimulus. The selection of the camera was based on the feasibility of modifying two of the camera components. The shutter speed was adaptable. (The camera also has a rear-loading compartment that facilitates quick film change without detachment of the camera from the main housing module.) (See figure 14)

Various cameras were tested for their ability to photograph a clear picture of the eye at a distance of seven inches as shown in Table I. Table I also lists the supplementary lenses used with each individual camera. These cameras were pilot tested in the eye-movement camera for analysis.

A comparison of inexpensive cameras on the market (see Table 2) shows that the Kodak XL-33 movie camera is best suited to photograph eye-movements with the newly designed eye-movement instrument. The Kodak XL-33 camera has a 9mm F/1:9 lens, with a 50mm six diopter lens added for close filming of the stimulus. Control of the shutter speed is maintained at 5 FPS by internal adjustment of the motor governor unit.

Camera Speed Control.

Eye movement photographs are normally taken at five frames per second. The standard shutter speed of a Super-8 movie camera is eighteen frames per second, thus necessitating an adjustment of the shutter speed of the camera. To adjust the shutter speed, a procedure for measuring camera shutter speed

FIGURE 14 SUPER-8 CAMERA: KODAK XL-33

Table 1

Cameras and Lenses Considered
For Use In the EM Camera

LIST OF CAMERAS:

*1. Kodak XL-33
Lens - Ektar 1.2 9mm
CDS electric eye - optical viewer
Speed control - 9 & 18 frames per second

2. Kodak XL-55
Lens - Ektar 9-21mm F/1.2 manual zoom
CDS electric eye - optical viewer
Dual speed control 9 & 18 frames per second

3. Focal XL-300
Lens - Shinkor F/1.1 10.5 - 30mm auto zoom
Thru-lens metering and viewing
Dual speed control - 9 & 18 frames per second

LIST OF SUPPLEMENTARY LENSES:

1. Vivitar -- 52mm close-up lenses: #1, #2, #3 - 6 diopter

2. Izuman - 52mm close-up zoom attachment lens - .1 - .49 m

3. Double convex - 2" lens Lens-ometer measurement 6X

*The XL-33 Camera was selected in favor of the other cameras.

Table 2

Comparison of Cameras Considered
For Use In the EM Instrument

(7" - Focal Distance)

Camera	Lens	FOCUS	ILLUMINATION	EYE-SIZE
	6-X	Fair	Fair	Too large
XL-33	Macro	Good	Fair	Good
	2"	Good	Good	Good
	6-X	Fair	Fair	Good
XL-55	Macro	Poor	Fair	Too large
	2"	Good	Fair	Good
	6-X	Poor	Poor	Good
XL-300	Macro	Poor	Poor	Too Large
	2"	Fair	Poor	Good

is required. In this study measurement of the camera shutter speed was done by using a stroboscope, (Strobotac model 1531-AB), that measured the shutter position by light impulses. The procedure for measurement was to focus an impulse from the stroboscope through the rear film access of the camera, and direct it through the camera lens. The stroboscopic light impulse was reflected onto the screen whenever the light impulse was synchronized with the shutter speed of the camera. The stroboscope meter would then give the reading of the lens shutter speed in revolutions per minute. A camera shutter speed of ten frames per second would read six hundred revolutions per minute on a stroboscope meter, (Ex. - 10 FPS x 60 sex. = 600 RPM). An increase or decrease of sixty revolutions per second would alter the camera shutter speed by one frame per second.

Extremes in voltage are necessary to change the camera shutter speed, due to a built-in motor governor control on the camera motor. A reading of 17 volts was necessary to change the camera shutter speed one frame per second, thus the change of shutter speed by means of a voltage change was not practical.

Although the external direct current (D.C.) power supply was not used to control the shutter speed, it was used as a permanent part of the Eye Movement Camera design, because of the constant voltage delivered to the camera, eliminating the chance of camera failure by use of weak batteries.

The Eastman Kodak Company Service Manual on the XL-33 Camera (Kodak 1969), explains a method of controlling the camera motor speed by adjusting the motor governor electrical contacts, (see Appendix II). The governor adjustment was made possible by drilling a one-eighth inch hole through the Kodak XL-33 camera housing unit directly over the motor governor access hole. The access hole allows the insertion of a watchmaker's screw-driver to adjust the governor mechanism for five frames per second.

Camera motor speed was attained by the alternate adjustment of two screws on the governor unit. Due to the sensitive nature of the governor contacts, many adjustments were made in order to set the shutter speed within the 5 per cent tolerance recommended by the company.

The XL-33 camera battery power supply was replaced by an external constant direct current power supply.

External Power Supply

It was found that the starting amperage of the XL-33 Camera motor was too great for the power supply when operating at six volts.

A power supply with greater initial drawing capacitance was constructed (see Figure 15). This new power supply was designed to operate at a constant 6.3 volts. Pilot testing of the power supply under a camera operating load of six volts and with supply line voltage surges of ten amperes, has operated with a voltage variance of two per cent.

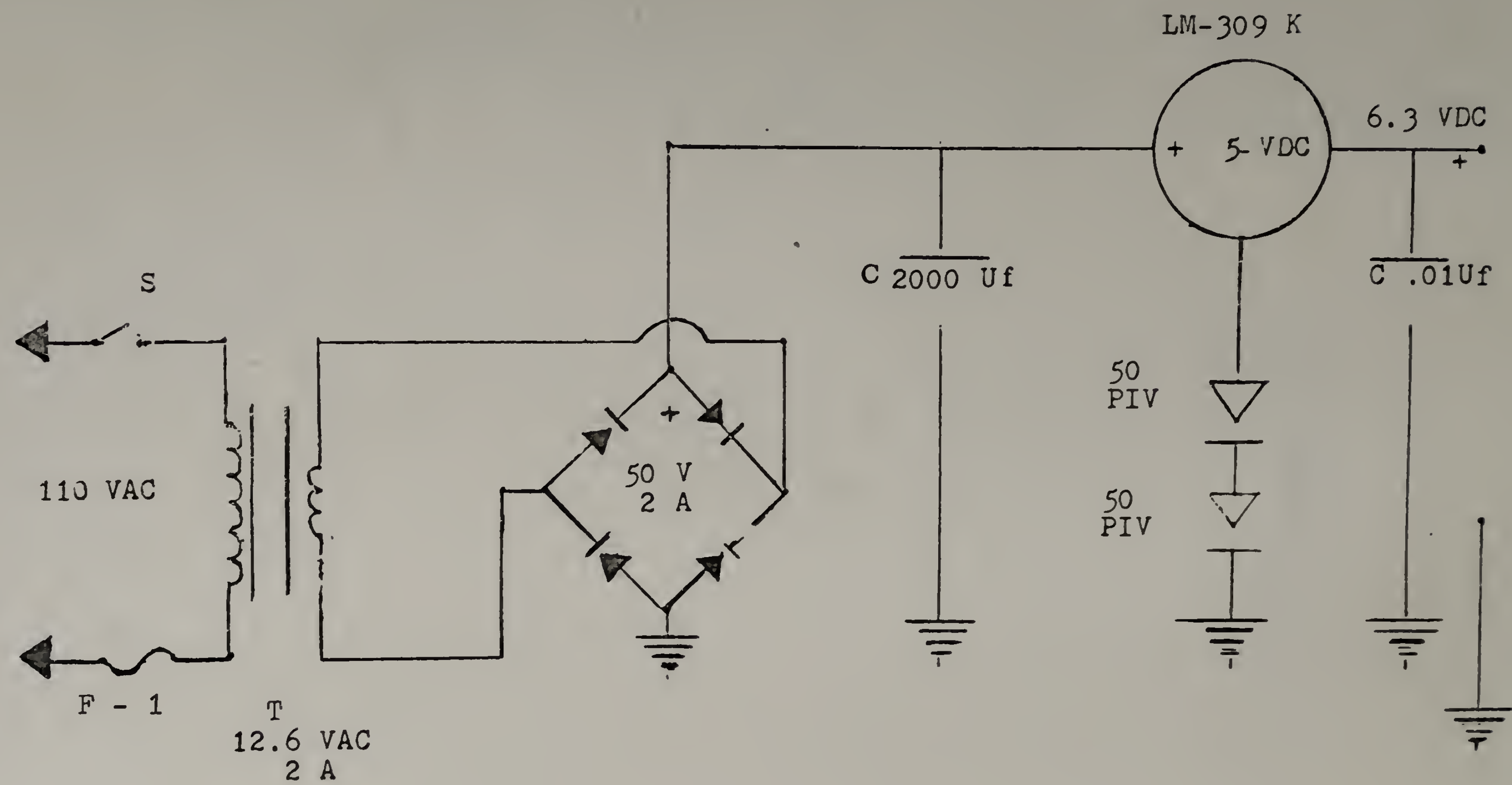


FIGURE 15 - POWER SUPPLY - CONSTANT VOLTAGE D.C.

Two-Way Mirror

The present eye-movement instrument uses a two-way mirror to reflect the eye image to the recording camera. The mirror is also utilized to transmit the presented stimulus to the eye. The high transmission two-way mirror allows the subject to view the stimulus without distortion.

In previous eye-movement instrumentation utilization of two-way mirrors varied from the present method used. In the Caban (1972), and Davis (1975) instruments, viewing of the stimulus was accomplished by using a two by three inch 70/30 two-way mirror. Viewing of the stimulus through the small mirror restricted the position of the eye in relation to the screen and the two-way mirror. Photography of the eye was also critical due to the small area of glass reflecting the eye image to the camera lens. This method necessitated a head strap to align the subject's eyes directly before the two-way mirror. The present eye-movement instrument utilizes a larger two-way mirror and a larger eye hole.

A range of two-way transmission mirrors were made available by the Foster Grant Company of Leominster. Selection of the 50/50 two-way mirror was based on a compromise between the transmission and reflective needs of the present eye-movement camera.

Through experimentation it was found that a two-way 50/50, eight by five inch mirror gave optimum results. This refinement allows a range of subject eye positions in front of the two-way mirror, because the subject is viewing the stimulus through eye slots in the eye illuminator, and the camera is photographing the whole eye through this eye slot as the subject's eye is viewing the stimulus presentation. The head movements are kept to a minimum by the placement of the subject's forehead comfortably on the front head rest. With this arrangement for eye alignment, accurate photographs can be taken. This procedure also eliminates the use of a bite bar and a restraining head strap to hold the head in alignment with the eye movement camera.

Visual Stimulus Reflector

In eye-movement photography, the position of the eye is analyzed in reference to the viewing stimulus. To insure an accurate recording of what the eye is viewing, the present eye-movement camera also photographs the image of what is on the screen as part of each frame.

This is accomplished by using a small 60 per cent reflective mirror to transmit the visual presentation from the rear-view projection screen to the camera. The selection of a sixty per cent reflective mirror was necessary to decrease the intensity of the stimulus reflection to the camera. The amount of reflective light emanating from the visual stimulus has to be equal in intensity to the amount of corneal light reflected from the eye.

The visual stimulus reflector is placed to the left of the right eye slot in the eye-illuminator. It is shaped with a slight convex angle. The convex design magnifies the image. The stimulus reflector is also positioned so that the image will appear on the bottom left of the developed eye photograph. (See Figure 6, p. 27) The final Super-8 film images show the eye and the visual stimulus being viewed.

Eye Illuminator

In order to meet the exposure conditions of motion picture film, a specific amount of light has to illuminate the eye. Eye illumination in this instrument was dependent on the amount of light passing through the two-way mirror. Trial photography of the eye using a 50/50 two-way mirror indicated that the light intensity reaching the eye was unsatisfactory, because it was below the level necessary for the production of clear images with the XL-33 Camera with a F/1:9 lens, and a 160 ASA film speed.

Increasing the light reflecting from the eye would allow the use of a slower lens speed. Decreasing the lens speed would increase the depth of field in the eye photographs. This method would produce images of the eye with greater corneal-iris contrast.

A method of increasing the illumination of the eye was devised by Davis (1975). This instrument used an eye-illuminator created by reflecting light from two fifteen watt fluorescent lamps through a clear plastic eye mask. This design provided the necessary illumination to photograph the eye, but was too large for the new design.

In the present instrument the eye-illuminator is constructed from a piece of polished plexi-glass stock. The eye-illuminator measures eight by four inches in length and is three-quarters of an inch thick. The plexi-glass stock was machined to fit over the bridge of the nose. Two oval eye slots were cut into the material, one and three-sixteenths inches, from the center line of the nose piece. These eye slots were inclined towards the eye at varing angles from ten to fifteen degrees. These angular eye slots are designed to direct light to the eye. The angular face of the slots are frosted to insure maximum light diffusion on the eye to reduce hot spots.

In the early stages of the eye-illuminator design a method of introducing external light to the illuminator was found to be unsuccessful. The unsuccessful method utilized three #123 lens type lamps implanted into the plexi-glass illuminator. It was found that these lamps failed to evenly illuminate the eye slots.

The present method used to illuminate the eye slots utilizes an eight inch, six watt, fluorescent lamp, placed on the top of the eye-illuminator. (See Figure 13). The lamp is mounted in a formica enclosure that is designed to fit over the top edge of the eye-illuminator. This enclosure is lined with a layer of aluminum reflective foil. An external on-off switch for the lamp is mounted on the top of the main instrument body.

Tests performed with this new eye-illuminator show a nine foot candle increase in the intensity of light reflected from the eye. Experimental photographs of the eye using this eye-illuminator have produced clear sharp images of the eye.

Rear Projection Transmission Screen

In the past few years two basic methods of projecting visual stimuli in eye-movement photography have been used. One is the projection of slides using a reflection from a front surface mirror onto a front projection screen. The second method is less complicated, i.e., slides are displayed directly onto a rear projection screen. This system also has the advantage of reducing keystoning.

The present eye-movement instrument uses rear projection method. In the initial planning of the instrument it was decided that the rear-projection screen method would make possible the construction of a more portable eye-movement camera. During experimentation, the rear-projection screen was found to transmit intensity light that is evenly dispersed on the screen.

The present eye-movement instrument utilizes a nine by eleven inch Polacoat LS-60 rear-view projection screen. The high gain screen is illuminated by the projection of 35mm slides from a Kodak carousel projector. Rear view projections from the screen are clear and bright.

The rear-view screen is fitted with a vinyl frame to protect its edges. The screen is designed for removal and storage in the main body of the eye-movement camera.

Audio Facility

The audio information that often accompanies slide presentations is reproduced by two one and one-half inch speakers placed on either side of the instrument body. The speakers are positioned approximately three inches from the subjects' ears, to prevent extraneous sound interferance.

The speakers are enclosed within preformed fiberglass units attached to the main body of the apparatus. Each speaker is glued to a three and one-half inch diameter grill. The speaker units are screwed into the fiberglass enclosures to facilitate removal.

Specifications of New Eye-Movement Camera

The completed eye movement camera specifications can be summarized as follows:

Specifications

Image size	9 x 11 inches
Field of view, angular	35 degrees maximum
Viewing distance	17 inches
Recording accuracy	plus or minus 2 degrees
Recording apparatus	Kodak XL 33 - Super-8 camera with internal electric drive
Size (without camera attachments)	12 inches wide x 23 inches long x 10 inches high
Weight	15 lbs.

Evaluation

Evaluation Modules

In evaluating the performance of the New Design Eye Movement camera the following three modules were utilized: an audio presentation module, a slide presentation module and a subject response module (see Figure 16). These three modules are described in the following sections.

Audio Presentation Module.

A stereo cassette player was used to supply narration from the first track of the cassette to the speakers on the Eye Movement camera while the

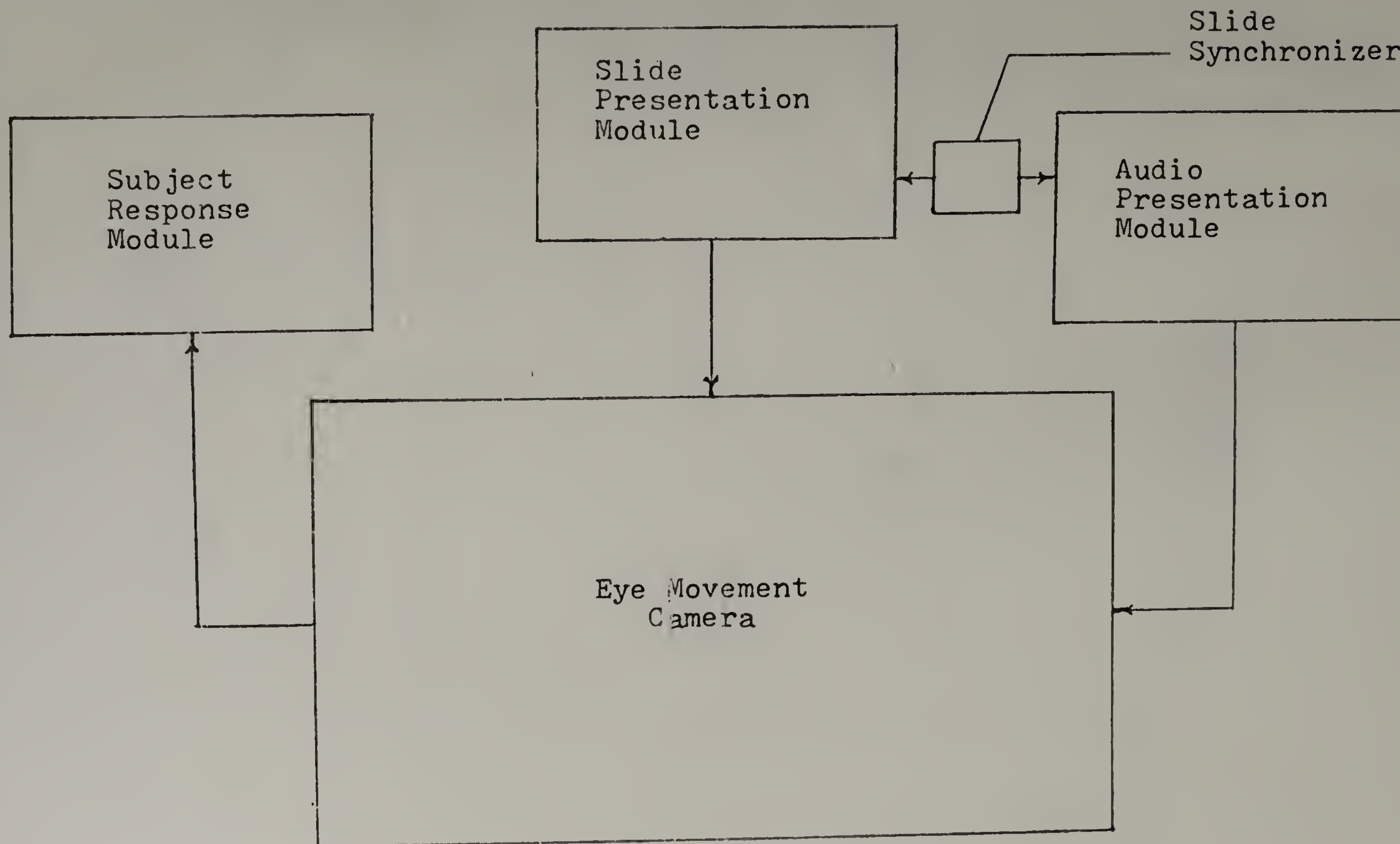


Figure 16 BLOCK DIAGRAM
EYE MOVEMENT CAMERA MODULES

second track supplies a pulse of the slide syncronizer.

Slide Presentation Module.

A Kodak Carousel was used to present 35mm slides to the subjects. The Carousel is activated by a pre-pulsed signal on the second track of a stereo cassette tape. A standard Kodak slide synchronizer is used to electrically pulse the Carousel projector.

A micro-switch was adapted to the Carousel projector body to activate the film camera during stimulus presentation. Lobes placed around the Carousel tray activate the microswitch, as the Carousel tray rotates these lobes spaced at specific intervals activate the eye movement camera.

Subject Response Module.

The subject's voice response is recorded by a hidden microphone placed approximately two inches away from his mouth. This microphone is connected by an extension cord to a second cassette recorder.

Evaluation Procedures

For the experimental eye movement instrument to be considered an improvement over earlier units the three specific evaluation criteria of accuracy, operation, size and cost had to be met. In order to examine the criteria of accuracy and operation it was decided to use the material and procedures previously used by researchers using similar instrumentation.

The testing procedure was based on a modified version of Rohwer's paired-associate learning task, originally used in research by Harris (1975) and Packard (1975). (See Appendix III) Each subject was presented with a concomitant paired-associate learning situation (a simultaneous presentation of two pair-associate relations in one frame). In both the pre-criterion and post-criterion sequences, each subject received treatments with six concomitant line drawing and print paired-visuals followed by a recall test of the pairs. The first object in the pair (accompanied with its audio label) was projected and the subject was expected to respond with the second object's name. During the learning phase, each subject could choose which combinations of line drawing and print stimulus to fixate on. All eye movements during the learning phase were recorded by the eye movement camera.

The subjects involved in the testing of the eye movement camera were recent graduates from the eighth grade in North Central Massachusetts. Of the fifteen subjects, nine were boys and six were girls. (See Appendix IV) The testing was done during one day of the students' summer vacation.

Accuracy.

Four specific measures constitute the accuracy criteria as applied to this eye movement instrument: 1) consistency of frame rate, 2) repeatability of work cycle, 3) clearness of image focus and 4) discernability of eye fixations.

Each measure was examined with regard to how well it had been met in the new instrument.

1) Consistency of frame rate. Measurements were conducted to determine the accuracy of the shutter speed of the Kodak XL-33 camera. It was found that during operation under load the camera operated at a shutter speed of five plus or minus 1/10 frames per second, which meets the accuracy needs of the design.

2) Repeatability of work cycle. During the test procedure with the 15 subjects a total of 180 slide changes and 3750 eye movement exposures were made. The various components worked smoothly and consistently without failure.

3) Clearness of image focus. The camera photographed 3750 frames of the subjects' eye movements. An examination of these exposures support the view that, except for frames where the eye was in motion (saccade), each image was in clear focus.

4) Discernability of eye fixation. The 3750 frames of the 15 subjects' eye fixations were examined with reference to the concomitant paired-associate stimuli and it was easy to discern the fixation point in each case. The distribution of fixations varied among subjects and were individually patterned. (See Table 3)

TABLE 3

Eye Fixation Scores

Test	Stimulus			Response	
	Fixations on Line Drawing	Fixations on Print	Center View	Fixations on Line Drawing	Fixations on Print
Pre-Criterion	39	27	2	33	28
(Subject 1) Post-Criterion	33	21	2	38	31
Pre-Criterion	40	36	2	32	18
(Subject 2) Post-Criterion	32	24	2	35	33

In tests performed to determine the accuracy of the new instrument's ability to photograph the stimulus reflection from the eye, it was found that at a viewing distance of seventeen inches and a lateral angular movement of thirty-five degrees, and a vertical eye motion of twenty degrees; the stimulus was measured with an accuracy of two degrees. This compares with a 2.5 degree accuracy of the Mackworth camera.

Operation.

The criteria of operation as applied to the new instrument is defined in terms of four specific measures: 1) simplicity, 2) picture and sound quality, 3) user comfort and 4) machine quietness. These measures were examined with regard to how well they had been met. A questionnaire was administered to the group (See Appendix V) to determine their views on the equipment operation. The group responses were evaluated for analysis. (See Table 4)

1) Simplicity. During the testing of the 15 subjects it was found that the eye movement camera and the associated modules could be set up in five minutes. Furthermore, there was no difficulty encountered in operating the various modules.

2) Picture quality. Subjects response to an evaluation questionnaire indicate that 87% stated picture clearness was "excellent". (See Table 4) .

TABLE 4

Subject Evaluation of New Design Eye Movement Camera

QUESTION	EVALUATION							
	Excellent		Good		Fair		Poor	
	No.	%	No.	%	No.	%	No.	%
1. Enjoy using equipment	6	40	9	60	-	-	-	-
2. Enjoy material presented	2	13	12	80	1	7	-	-
3. Ease of use	8	53	7	47	-	-	-	-
4. Comfort of use	6	40	9	60	-	-	-	-
5. Picture clearness	13	87	2	13	-	-	-	-
6. Sound presentation	10	67	3	20	2	13	-	-
7. Quietness	8	53	7	47	-	-	-	-
8. Enjoy as a test instrument	5	34	9	60	1	6	-	-
9. Presentation of directions	9	60	5	34	1	6	-	-
10. Enjoy oral response over written response	6	40	7	47	2	13	-	-
Total Evaluations = 150 =	73		69		8		0	
Total Percentages = 100% =		49		46		5		0

(N=15)

3) User comfort. To determine how a typical user might feel about the eye movement camera the questionnaire contained an item on user comfort. Ninety-five percent (95%) of the students rated the instrument's comfort as "good" or "excellent". (See Table 4)

4) Machine quietness. The same group of subjects responded to the questionnaire item on quietness with 53% feeling that the instrument was "excellent" in this dimension and the remaining 47% felt that it was "good". (See Table 4)

Size and Cost.

Four items comprise the specific measures used to evaluate the new instrument in terms of size and cost: 1) portability, 2) sturdiness, 3) aesthetic form and 4) reasonable cost. These measures were examined to see how well they were met.

1) Portability. The new eye movement instrument is 23 x 12 x 10 inches in size and weighs 15 pounds. When compared with earlier instruments it is definitely smaller and lighter in weight, and can be described as portable.

2) Sturdiness. The instrument under normal usage during the testing procedure experienced no difficulty. The nature of the construction supports the view that the eye movement camera will work as per design and will withstand normal usage.

3) Aesthetic form. The housing has a smooth poly-glass resin finish and occupies a minimum space. The logical placement of components within the housing and the efficient use of space creates an aesthetic relationship giving the instrument a pleasant appearance.

4) Reasonable cost. The cost of materials for the eye movement camera and its related operating modules are listed below. Also listed is a rough approximation of labor costs.

Materials

	Item	Cost
1.	Main housing	$18.00
2.	Rear transmission screen (Polacoat material LS-60)	12.00
3.	Two-way 50/50 mirror	7.00
4.	Main housing speakers (2)	3.00
5.	Eye-illuminator	2.00
6.	Eye-illuminator lamp and fixture	6.00
7.	Kodak XL-33 Super-8 Camera	64.00
8.	Camera 6 diopter lens	2.00
9.	Assorted electrical adaptors	7.00
10.	Power supply	16.00
	Total ----	$137.00

Labor

	Item	Cost
1.	Main housing (@ $6/hr.)	$100.00
2.	Eye illuminator	25.00
3.	Power supply (6.3 volt)	20.00
	Total - - - - -	$145.00
	Total materials and construction	$282.00

A comparison of the construction costs of the new design and earlier instrumentation, using the reflective eye movement recording technique, serves to illustrate how the cost of these units has decreased. (See Table 5) The construction cost of approximately $300.00 may be considered quite reasonable for this eye movement camera and therefore it is assumed to have met the design criteria of low cost. The Mackworth eye movement camera, available from the Polymetric Co., lists for $2,360.00. Table 6 compares the manufacturing cost of the present eye movement camera with other instrumentation. For this second comparison the new design is assumed to have a market price of $900.00 which includes a 200% profit margin. Again it can be seen that the new design is potentially much lower in cost.

TABLE 5

Comparative Constructive Costs of Reflective Eye Movement Instrumentation

METHOD	RECORDING CAMERA	OUTPUT	CONSTRUCTION COST	COMPANY
Coffing	Concord Television	Video Tape	$6,200	Not Available
Caban	Lecima Super-8 (External Pulse)	Film	$1,000	Not Available
Davis	Konica Super-8 (Modified for external drive)	Film	$500	Not Available
New Design	Kodak Super-8 XL-33 (Internal speed adjustment)	Film	$300	Not Available

TABLE 6

Comparative Costs of Commercially Available Eye Movement Instrumentation and New Design

METHOD	ACCURACY	OUTPUT	PRICE	COMPANY
Wide Angle Mackworth Camera V-1166	$\pm 2.5^o$	Photographs or Video Tape	$2,360	Polymetric Company New Jersey
Honeywell Oculometer	$\pm 1.0^o$	Digital, Analog	$40,000	Honeywell Radiation Lexington MA
Double Purkinje Image Eye Tracker	$\pm 1.5^o$	Analog Output	$20,000	Stanford Research Institute California
New Design Portable Eye Movement Camera	$\pm 2.0^o$	Photograph (May be adapted to video)	$900 (with an estimated 200% profit margin)	Not presently available

CHAPTER IV

DISCUSSION AND CONCLUSION

Several instruments for measuring eye movements have been developed in the past decade. Using Mackworth's Wide Angle eye movement camera as a model, the eye movement camera described in this study follows the earlier developmental lines but explores the design parameters of accuracy, operation, size and cost in an effort to develop an inexpensive, easily transported and used instrument. Such an eye movement camera could find effective use in schools and thus facilitate the task of identifying, in typical educational settings, the most suitable visual instruction for individual students. Thus, the focus of this project was the development of a new eye movement instrument that would make research easier and less costly.

The camera used in this instrument was a Kodak Super-8 XL-33 modified to operate at five frames per second. Power for the camera was supplied by a specially designed regulated power supply. The camera located on top of the housing photographs the subject's eye via a reflection on a 50/50 two-way mirror. The total weight of the instrument is fifteen pounds and its overall dimensions are smaller than the Mackworth eye movement camera and those of Coffing (1971), Caban (1972), and Davis (1975).

In terms of features, it was necessary to design a special unit with sufficient power to supply the camera six volts direct current with the ability of handling ten ampere line surges under operating load. A second feature which required a good deal of experimentation was the eye illuminator unit which is constructed from a piece of polished plexi-glass and utilizes a six watt fluorescent lamp to supply light to photograph the eye.

The stimulus presentation screen used in this camera is a Polacoat LS-60 rear-view projection screen which supplies a clear, bright image having even light distribution.

Several external modules were used as part of the evaluation process. They are a modified Kodak Carousel 850 projector, an Amprex stereo cassette recorder, a Panasonic cassette recorder and a Kodak slide synochonizer.

The new instrument was tested with materials previously used in several eye movement studies. Fifteen eighth-grade children were used as subjects in the camera evaluation. An analysis of the eye movement camera in operation and of the resulting film supports the conclusion that the design criteria of accuracy and operation were met. The questionnaires given the subjects showed that ninety-five per cent of the subjects in the test rated the eye camera "good" to "excellent" in all respects. (see Figure 19). A high subject rating was given to picture clarity (87% "excellent"), and the sound presentation (67%

"excellent"). The next highest ratings on instrument usage were in the following areas: ease of use (53% "excellent"); and quietness (53% "excellent"). From these responses it appears that the goal of constructing an eye movement camera that is easy and comfortable to use has been met.

In tests performed to determined the accuracy of the new instrument to photograph eye reflections, it was found that at a viewing distance of seventeen inches, the stimulus reflected from the eye could be measured with an accuracy of two degrees. The Mackworth camera claims a 2.5 degree accuracy.

In terms of size and cost the instrument can be considered to have met the criteria. Its dimensions and weight are less than earlier models. The developmental costs of $288.00 and estimated $900 market price can be favorably compared with the Mackworth eye movement camera listing for $2,360, even when a profit margin is factored in, the new instrument is significantly less expensive.

The new eye movement camera seen in figures 17 and 18 is one solution to previous design limitations. This camera, lighting and housing approach, presents an economical and efficient manner of recording eye movements. There is a need to further explore the use of the new instrument under actual experimental conditions. While the test procedures used to evaluate the eye movement camera demonstrated no shortcomings, only actual operation over an extended period of time will substantiate these encouraging early results. There is no doubt that continual use under different settings could disclose aspects of the

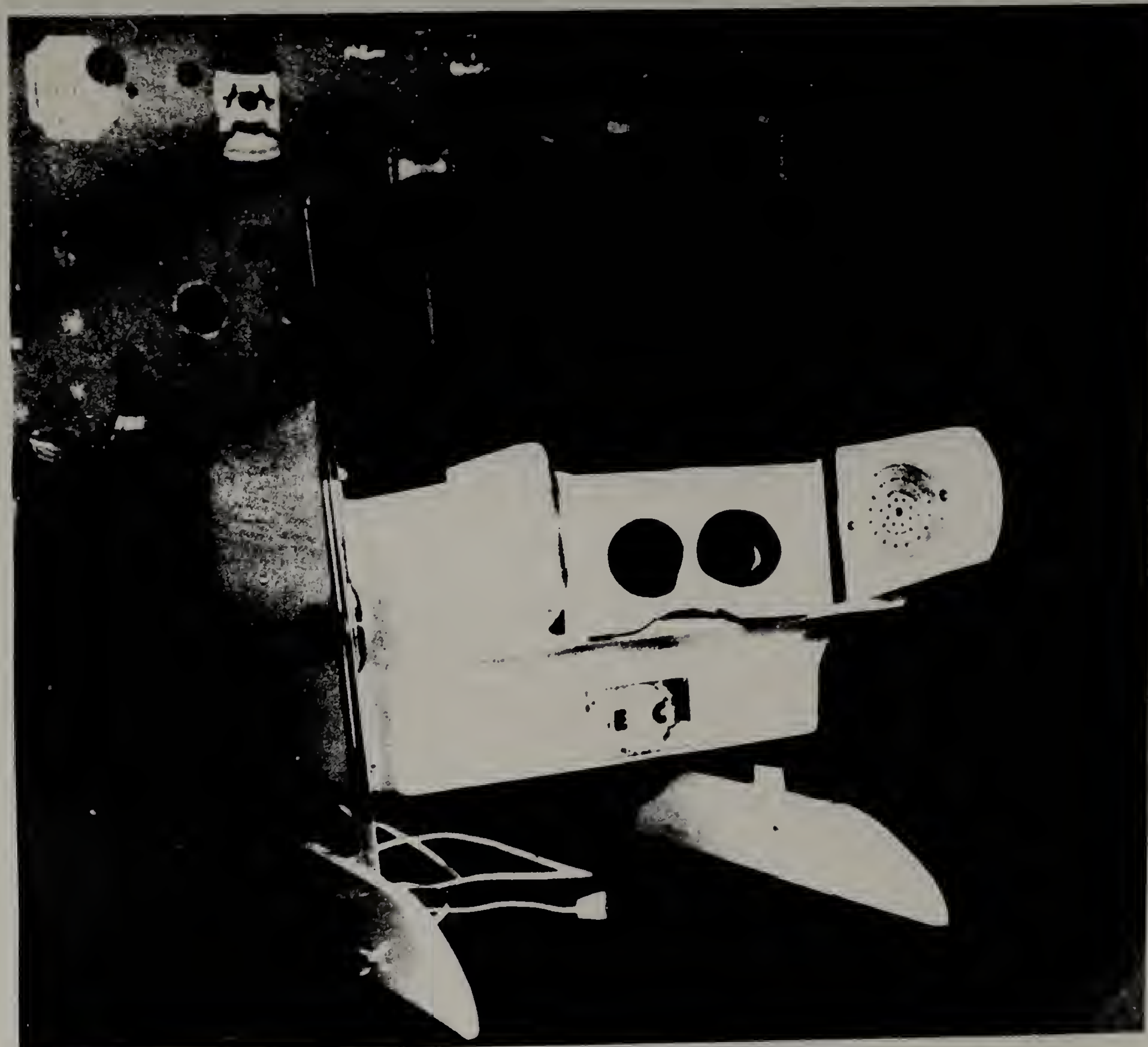


FIGURE 17 PHOTOGRAPH OF NEW EYE MOVEMENT CAMERA

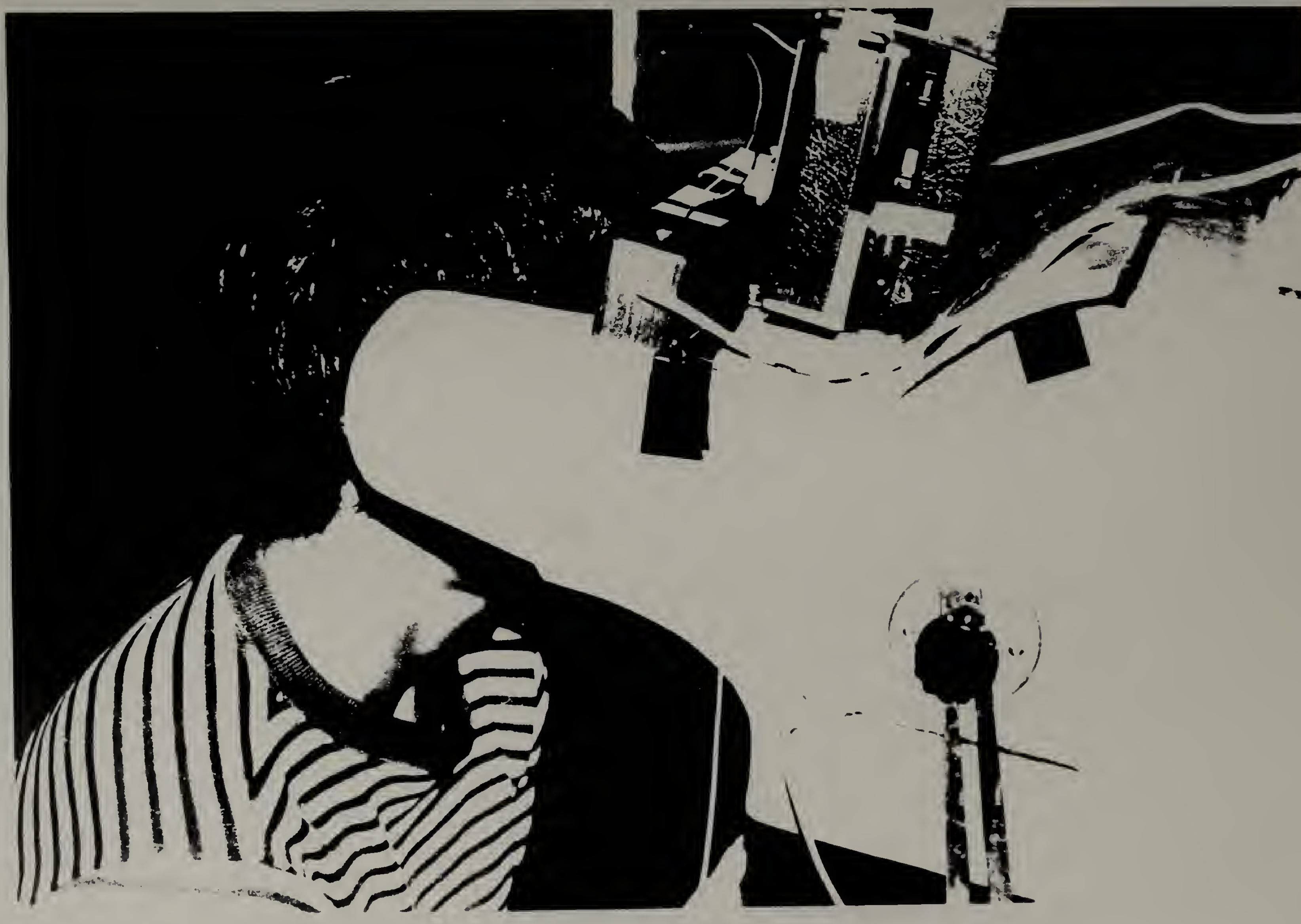


FIGURE 13. [illegible] EYE MOVEMENT CAMERA IN USE

instrument that might require further development.

The fact that this new eye movement instrument has been built will hopefully encourage other eye movement researchers to build similar units. This new instrumentation could be an important tool in furthering research in eye movement technology.

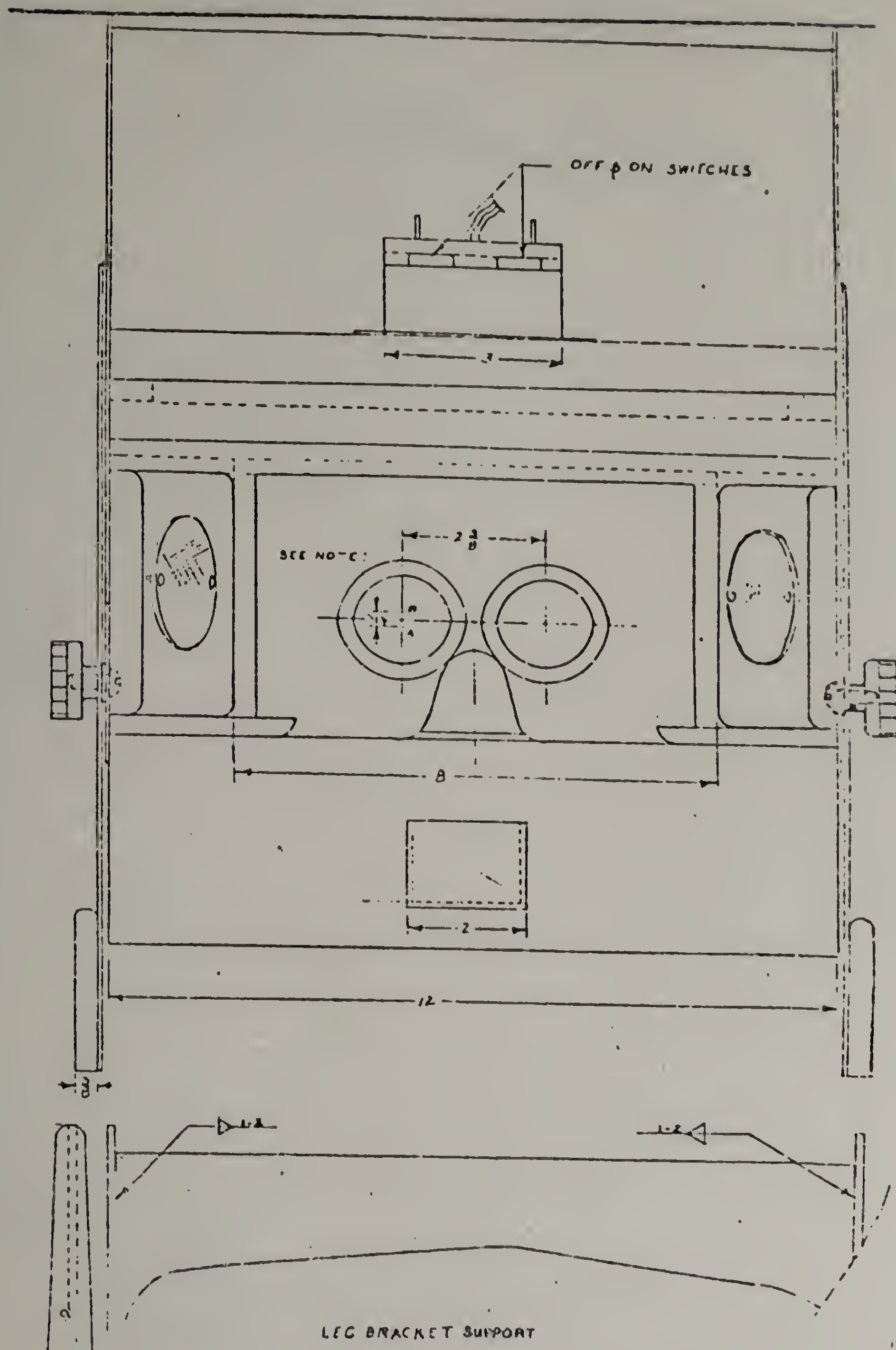
APPENDICES

APPENDIX I

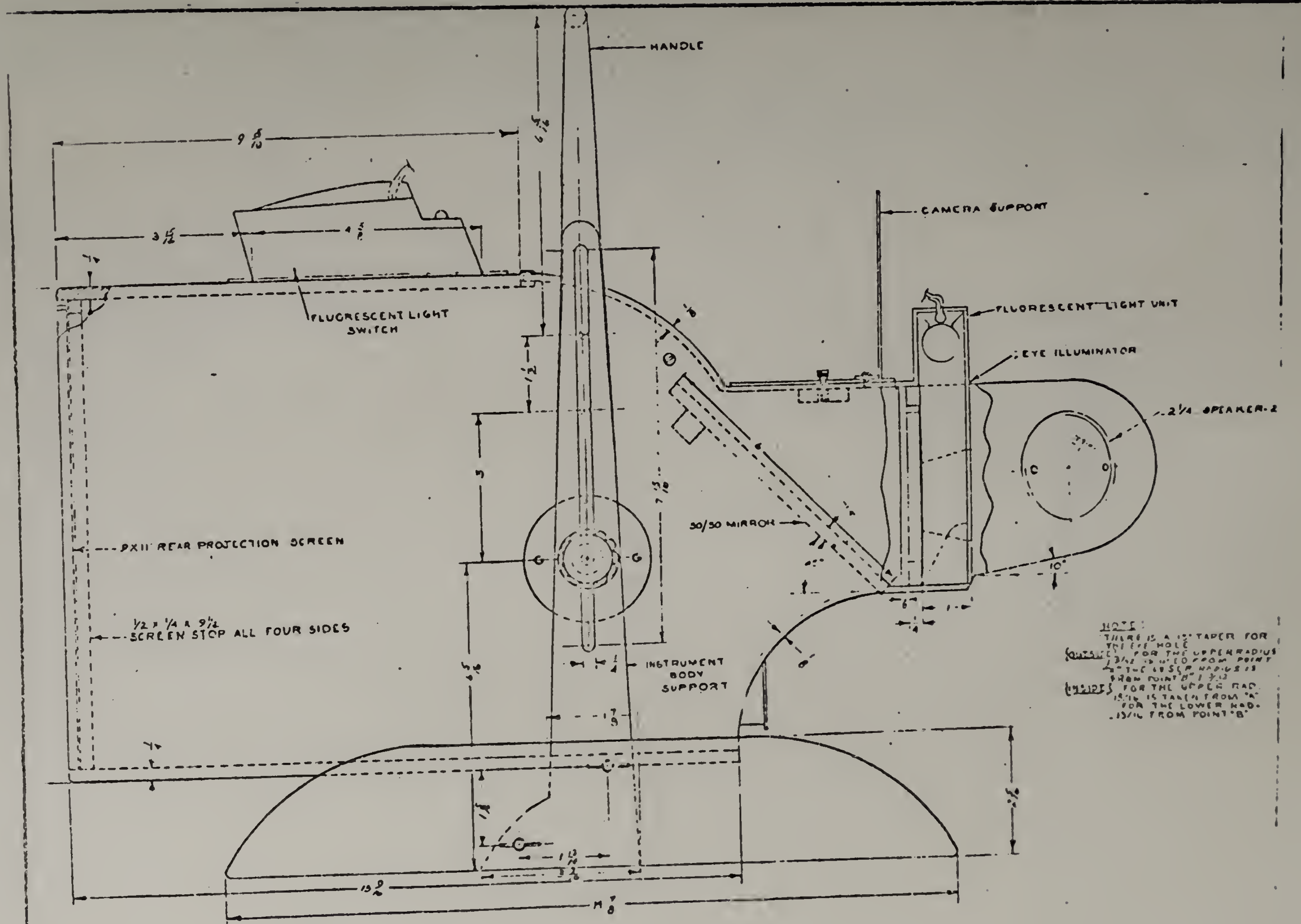
Scale Layout of New Design

Eye Movement Camera--Front

and Side Views



FRONT VIEW


HANDLE
CAMERA SUPPORT
FLUORESCENT LIGHT UNIT
EYE ILLUMINATOR
2¼ SPEAKER-2
FLUORESCENT LIGHT SWITCH
30/30 MIRROR
8X11 REAR PROJECTION SCREEN
½ x ¼ x 9½ SCREEN STOP ALL FOUR SIDES
INSTRUMENT BODY SUPPORT

SIDE VIEW

APPENDIX II

Kodak XL-33 Super-8 Camera

Service Manual

JUNE 1972

775128

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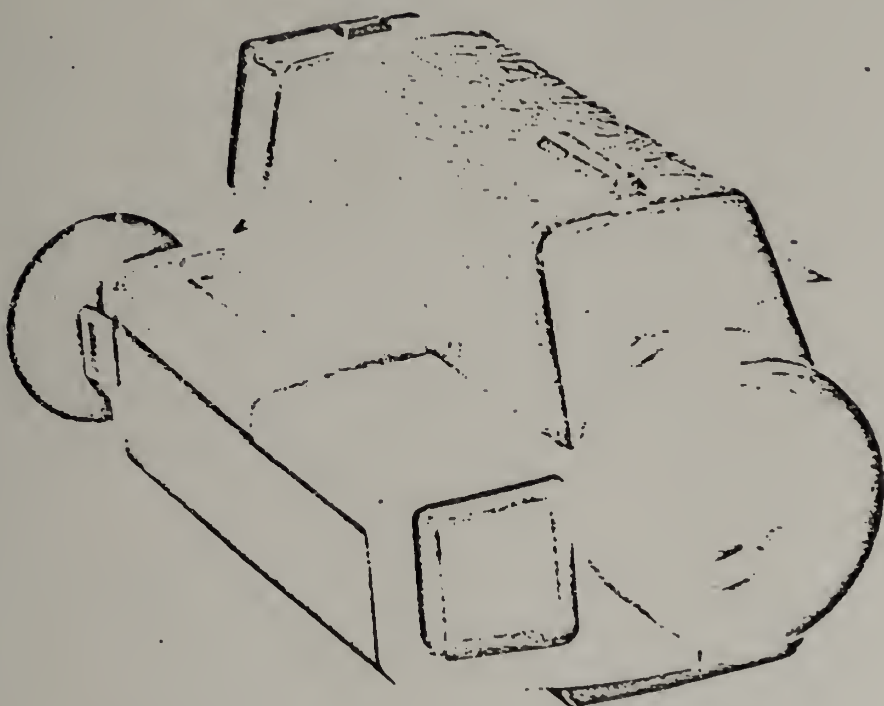
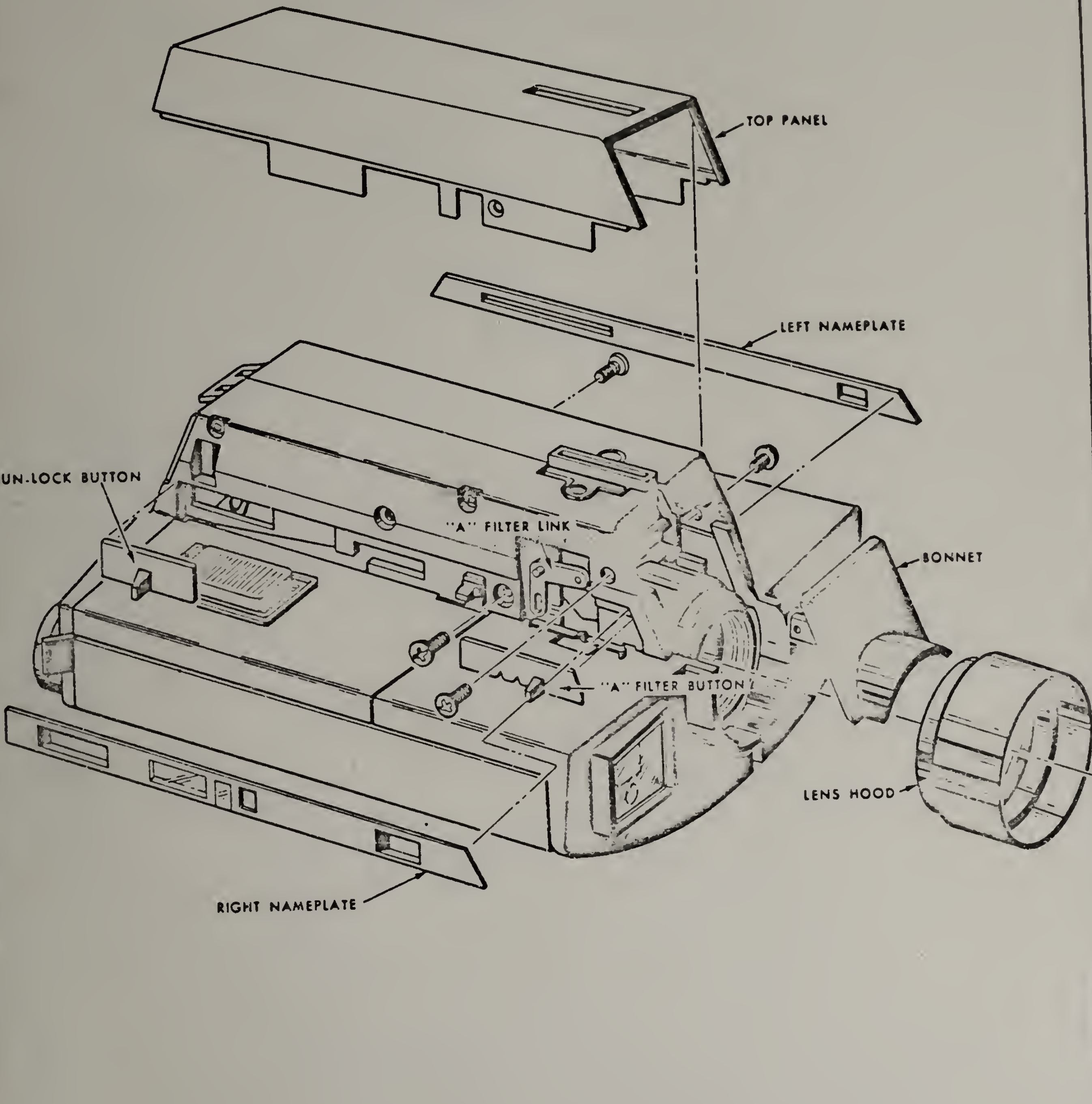
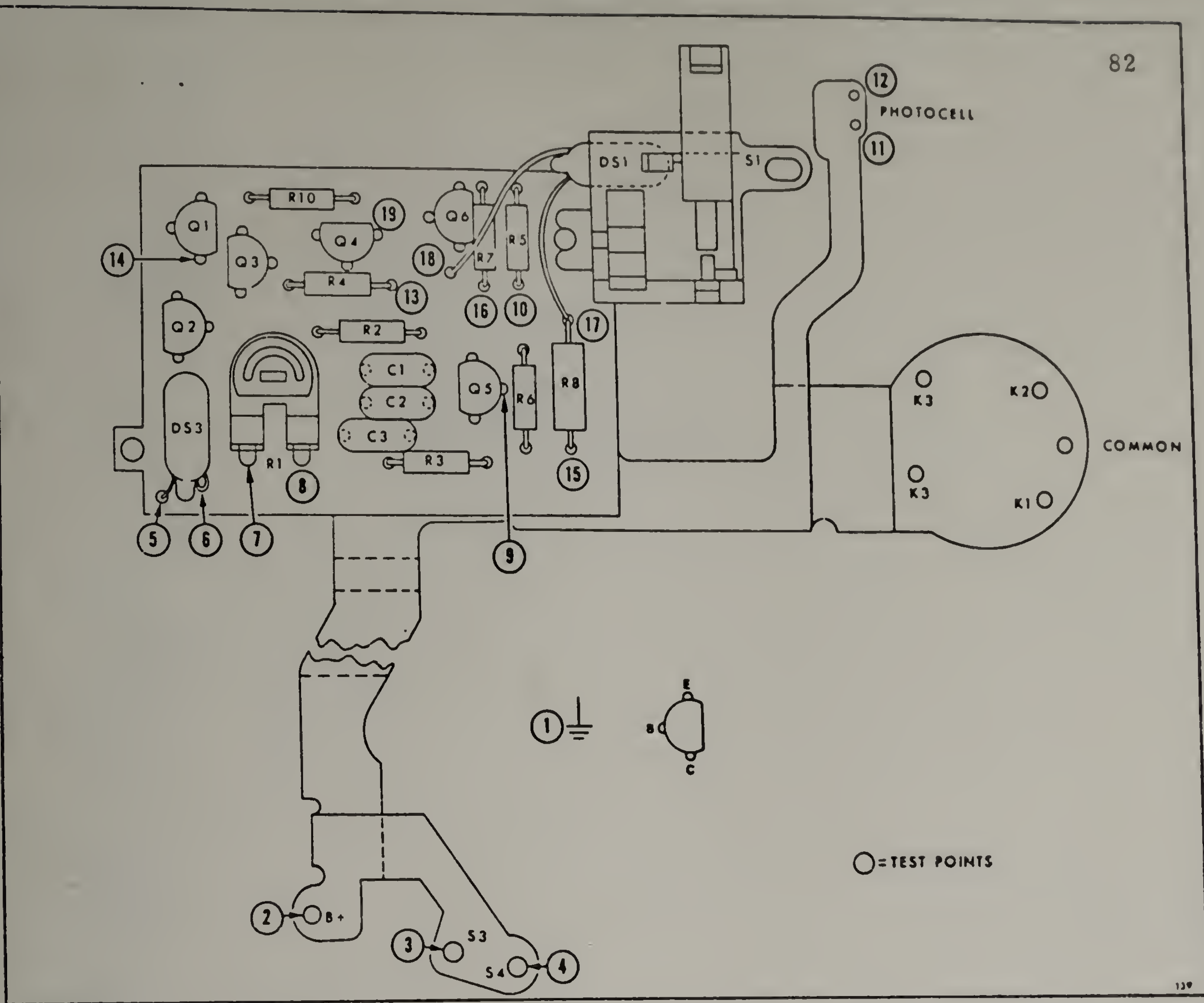
Servicing the

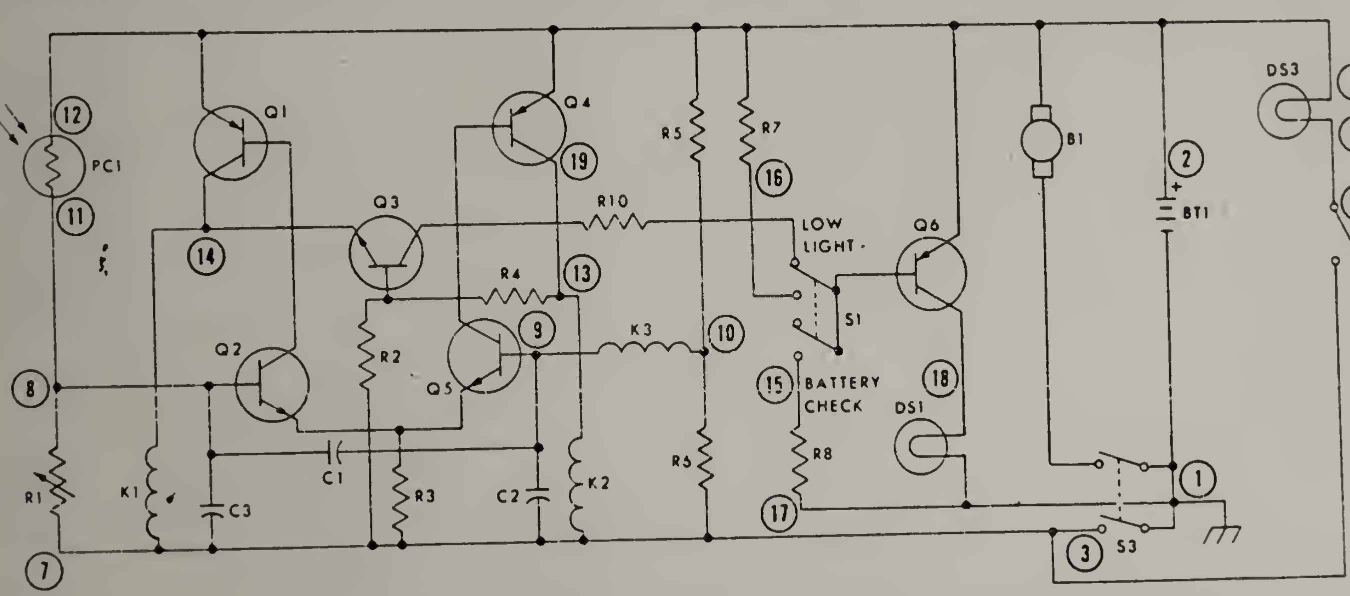
KODAK XL-33 MOVIE CAMERA



EASTMAN KODAK COMPANY • CUSTOMER EQUIPMENT SERVICES DIVISION
SERVICE ENGINEERING DEPARTMENT
800 LEE ROAD, ROCHESTER, NEW YORK 14650


TOP PANEL
LEFT NAMEPLATE
RUN-LOCK BUTTON
"A" FILTER LINK
BONNET
"A" FILTER BUTTON
LENS HOOD
RIGHT NAMEPLATE





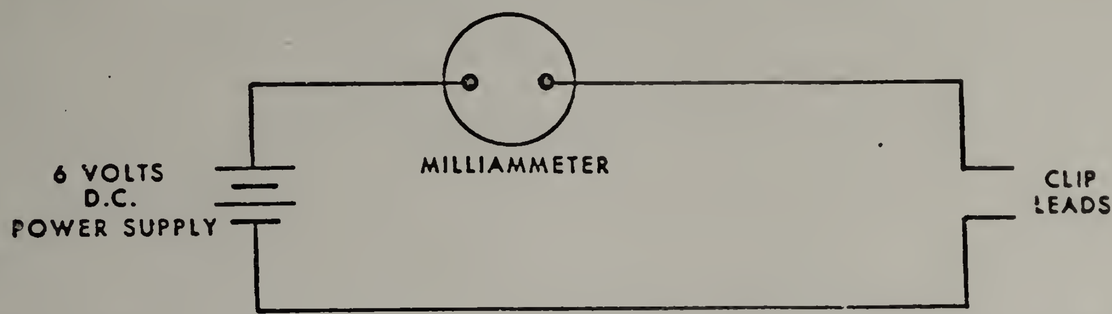
○= TEST POINTS

Wiring and Schematic Diagrams for the KODAK XL-33 Movie Camera

2.1 POWER SUPPLY

2.1.1 DESCRIPTION

A variable power supply for this camera is extremely valuable for trouble-shooting, especially one that has a milliammeter in series with the motor so that current drain can be measured through the camera's electrical system. This power supply must be full-wave rectified ac, with less than 0.1% ripple. Eastman Kodak Company does not make a power supply for this purpose since there are many commercial power supplies available which meet the necessary requirements. A less expensive tool, suitable for infrequent use, can be made using the schematic and information below:



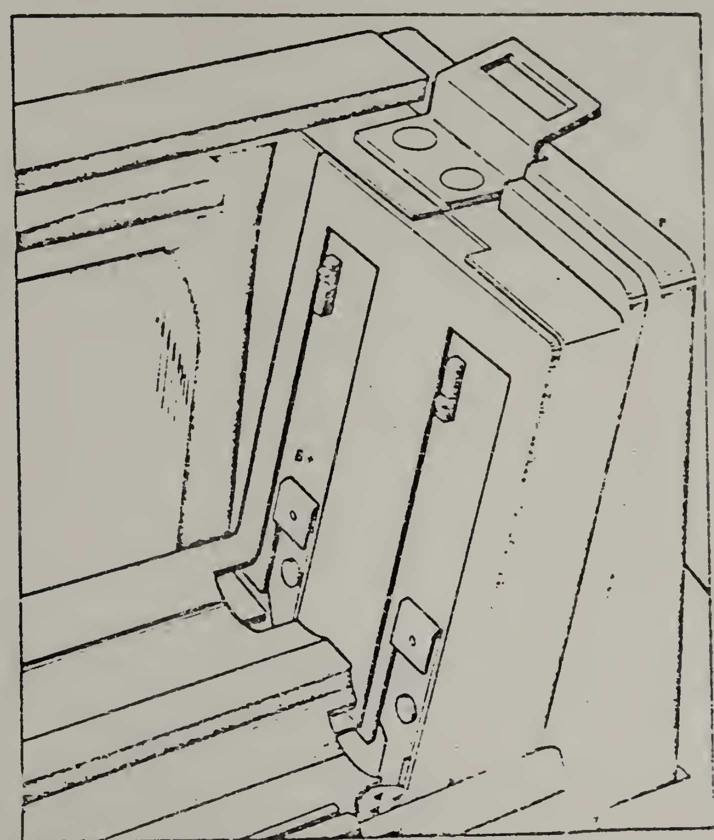
Power supply: four AA-size, 1.5V manganese-alkaline batteries or 6V battery, or 6V full-wave rectified ac, variable or fixed.
Milliammeter: 0-1000 ma less than 0.3-ohm resistance.

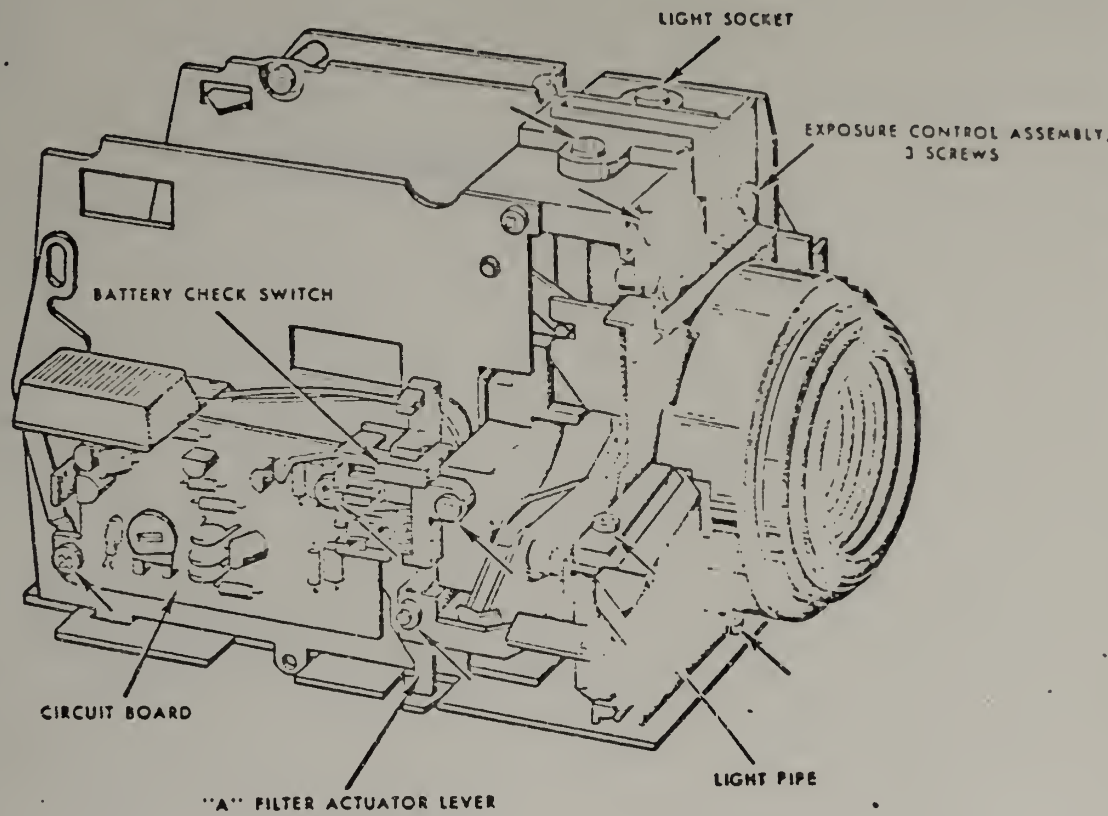
2.1.2 To use a power supply, adjust voltage to 6 volts if a variable power supply is used. Voltage supplied by four good AA-size, manganese-alkaline batteries, or by one 6V battery is also satisfactory.

2.1.3 Open the battery compartment cover and connect the positive (+) lead to the terminal indicated and the negative (-) lead to any part of the camera case.

2.1.4 The milliammeter should indicate a "0" reading. If current flow is indicated, refer to Instruction 6.1.

2.1.5 Depress the exposure release - camera should run in a normal manner and the current drain should not exceed 350 ma. If the camera does not run or draws excessive current, refer to Service Hints, Section 6.1.





3.8.6 Remove the three screws securing the circuit board and battery check switch.

3.8.7 Remove the retaining ring that secures the Type A filter actuator lever and remove the lever.

3.8.8 Loosen the screw that secures the photocell light pipe and remove the light pipe.

3.8.9 Remove the two screws securing the movie light socket and remove the socket.

3.8.10 Remove the three screws securing the exposure control assembly to the shutter housing and remove the circuit board assembly, switch block, and exposure control assembly from the camera.

4.1 SPEED

4.1.1 At a voltage input of 4.0 to 6.0 volts, the speed should be 18 ± 1 fps and 9 ± 1 fps with or without film.

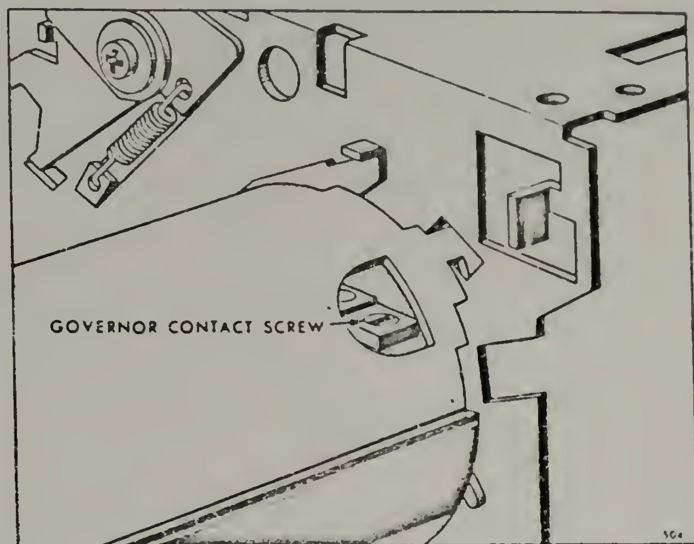
4.1.2 Use a stroboscope on motor shaft; 2750 rpm to 3080 rpm OR

NOTE: Speed selector set at either 18 fps or 9 fps.

4.1.3 Count the number of revolutions of the take-up drive in 17 seconds; count will be very near fps.

4.1.4 Remove the left side case assembly (3.7), exposing the motor governor access hole.

4.1.5 Rotate the camera mechanism so that one of the governor contact screws shows in the hole, and mark it for identification. Turn the screw out far enough so that electrical contact is broken between it and the contact.



4.1.6 Connect a power supply to the camera. Positive (+) lead on red motor wire and negative (-) lead to the camera case.

4.1.7 Run the camera at a voltage input of 6.0 volts and adjust the unmarked governor screw to obtain a motor speed of 2900 rpm.

4.1. Adjust the marked screw so that it just makes electrical contact and results in a slight increase of motor speed. 10 to 20 rpm of the motor.

4.1.9 Hold camera mechanism back with finger while running at 6.0 volts input. Current drain at the stall point should be considerably greater than 500 ma and the motor should feel strong. If the motor stalls at approximately 500 ma and does not feel to be driving powerfully, one of the governor contact screws may not be making contact. Adjust as needed. If motor continues to stall at 500 ma or less, motor may be defective. Replace motor (3.13).

4.1.10 At room temperature, the current drain shall not exceed 350 ma, including the motor and the exposure control.

4.2 FOCUS

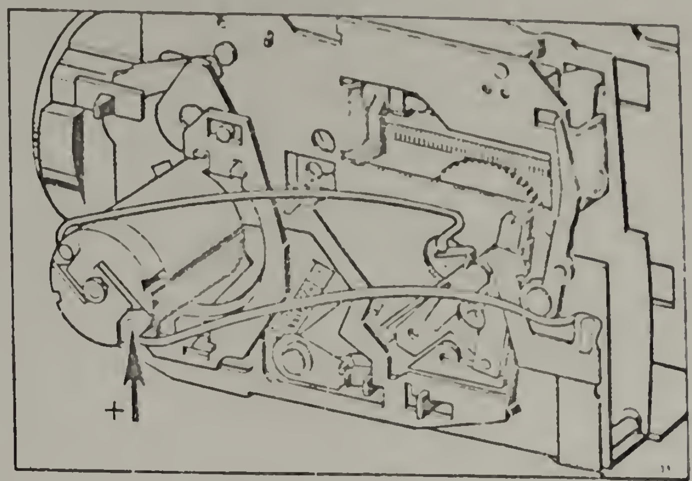
4.2.1 The *KODAK* XL33 Movie Camera is a fixed-focus camera. Optimum focus is considered to be at 17 feet, 5 inches. Acceptable focus limits are from 10 feet to 30 feet.

4.9 END-OF-FILM INDICATOR

4.9.1 The end-of-film indicator light should light in the bottom of the viewfinder when there is approximately 3 feet of film remaining in a film cartridge.

4.9.2 The end-of-film switch is activated by the footage indicator. The switch can be checked by removing the left side case assembly (3.7).

4.9.3 Connect a 6V power supply, positive (+) to the red motor lead and negative (-) lead to the camera case.



4.9.4 Depress trigger halfway to activate the exposure control assembly and activate the end-of-film switch manually.

The end-of-film light should light when contact is made and should go off when contact is broken.

4.9.5 Remove right side case assembly (3.4).

4.9.6 Check continuity of lamp DS3. Replace if defective. (See wiring diagram on Foldout, Page No. 35.)

4.9.7 Check for continuity from lamp DS3 to B+ and to switch S4. Circuit board will have to be replaced if defective. (See wiring diagram on Foldout, Page No. 35.)

4.10 BATTERY CHECK

4.10.1 The battery check light should light when the battery check button is depressed if the battery voltage is greater than 3.5 volts.

4.10.2 Make sure batteries are good before proceeding.

4.10.3 Remove the left side case assembly (3.7) and the right side case assembly (3.4).

4.10.4 Check continuity of battery check lamp DS1. (See wiring diagram on Foldout, Page No. 35.)

4.10.5 Depress the battery check switch and check for continuity from the base of Q6 to R8. (See wiring diagram on Foldout, Page 35.)

4.10.6 Depress the battery check switch and check for continuity from the base of Q6 to R7. (See wiring diagram on Foldout, Page No. 35.)

4.10.7 If the preceding continuity checks cannot be met, it will be necessary to change the battery check switch S1 or the circuit board (3.8).

APPENDIX III

Stimuli Presentation to Subjects

Script for Slide Presentation

Script for Slide Tape Presentation to Subjects

This experiment involves remembering things that are grouped together in pairs:

Learning in pairs SLIDE 1

It is not difficult, but it will require your full concentration. You will be presented with pairs of things that must be remembered together. For example, you might hear the sentence, "The brick breaks the window."

The brick breaks the window SLIDE 2

At the same time you will see helpful information on the screen in front of you. A number of these pairs will be presented. These will be called, "Pairs to Remember."

Pairs to Remember SLIDE 3

Try to remember as many as possible.

In the test part, you will then be asked to name out loud the second part of a pair when you are presented with the first part. In our example when the brick

Brick SLIDE 4

is presented alone, you should answer out loud "window." To repeat, you are asked to study each of the pictures of paired objects, "Pairs to remember," as they appear on the screen, while listening to the verbal description of the

Pairs to remember SLIDE 5

objects in order to learn which objects are presented together. You will be asked to name the missing object in each pair when shown the other object of that pair.

Pairs SLIDE 6

Now look at each number in turn as I call them:

1, 2, 3, 4, 5 SLIDE 7

Number One. Number Two. Number Three. Number Four. Number Five.

Now you will be presented the first set of slides.

Pairs to Remember SLIDE 8

The carrot taps the barrel. SLIDE 9

The foot kicks the School. SLIDE 10

The bat breaks the cup. SLIDE 11

The hair fills the pipe. SLIDE 12

The hand throws the hat. SLIDE 13

The iron melts the candy. SLIDE 14

Now give your answers out loud.

Test	SLIDE 15
Iron	SLIDE 16
Foot	SLIDE 17
Bat	SLIDE 18
Carrot	SLIDE 19
Hand	SLIDE 20
Hair	SLIDE 21

Now here is the second set to remember:

Pairs to Remember	SLIDE 22
The doll opens the book.	SLIDE 23
The letter strokes the beans.	SLIDE 24
The wheel spins the fish.	SLIDE 25
The can marks the butter.	SLIDE 26
The spoon rolls the egg.	SLIDE 27
The fork cuts the cake.	SLIDE 28
The fire burns the bed.	SLIDE 29
The celery hits the stairs.	SLIDE 30
The guitar occupies the sink.	SLIDE 31
The rock cracks the bottle.	SLIDE 32
The arm holds the break.	SLIDE 33
The shovel lifts the popcorn.	SLIDE 34

TEST	SLIDE 35
Fire	SLIDE 36
Doll	SLIDE 37
Spoon	SLIDE 38
Guitar	SLIDE 39
Can	SLIDE 40
Shovel	SLIDE 41
Letter	SLIDE 42
Wheel	SLIDE 43
Celery	SLIDE 44
Rock	SLIDE 45
Fork	SLIDE 46
Arm	SLIDE 47

Now here is the third set for you to remember.

Pairs to Remember	SLIDE 48
The ruler divides the sandwich.	SLIDE 49
The elephant kicks the clock.	SLIDE 50
The button rubs the comb.	SLIDE 51
The string secures the box.	SLIDE 52
The cow jumps the tent.	SLIDE 53
The clown chews the banana.	SLIDE 54
The needle pops the balloon.	SLIDE 55
The rope touches the eye.	SLIDE 56
The dog closes the gate.	SLIDE 57

The car upsets the wagon.	SLIDE 58
The frog leaps the cage.	SLIDE 59
The blanket covers the tree.	SLIDE 60

Now give your answers out loud.

TEST	SLIDE 61
Needle	SLIDE 62
Ruler	SLIDE 63
Cow	SLIDE 64
Dog	SLIDE 65
String	SLIDE 66
Blanket	SLIDE 67
Elephant	SLIDE 68
Button	SLIDE 69
Rope	SLIDE 70
Car	SLIDE 71
Clown	SLIDE 72
Frog	SLIDE 73

And here is the last set to remember.

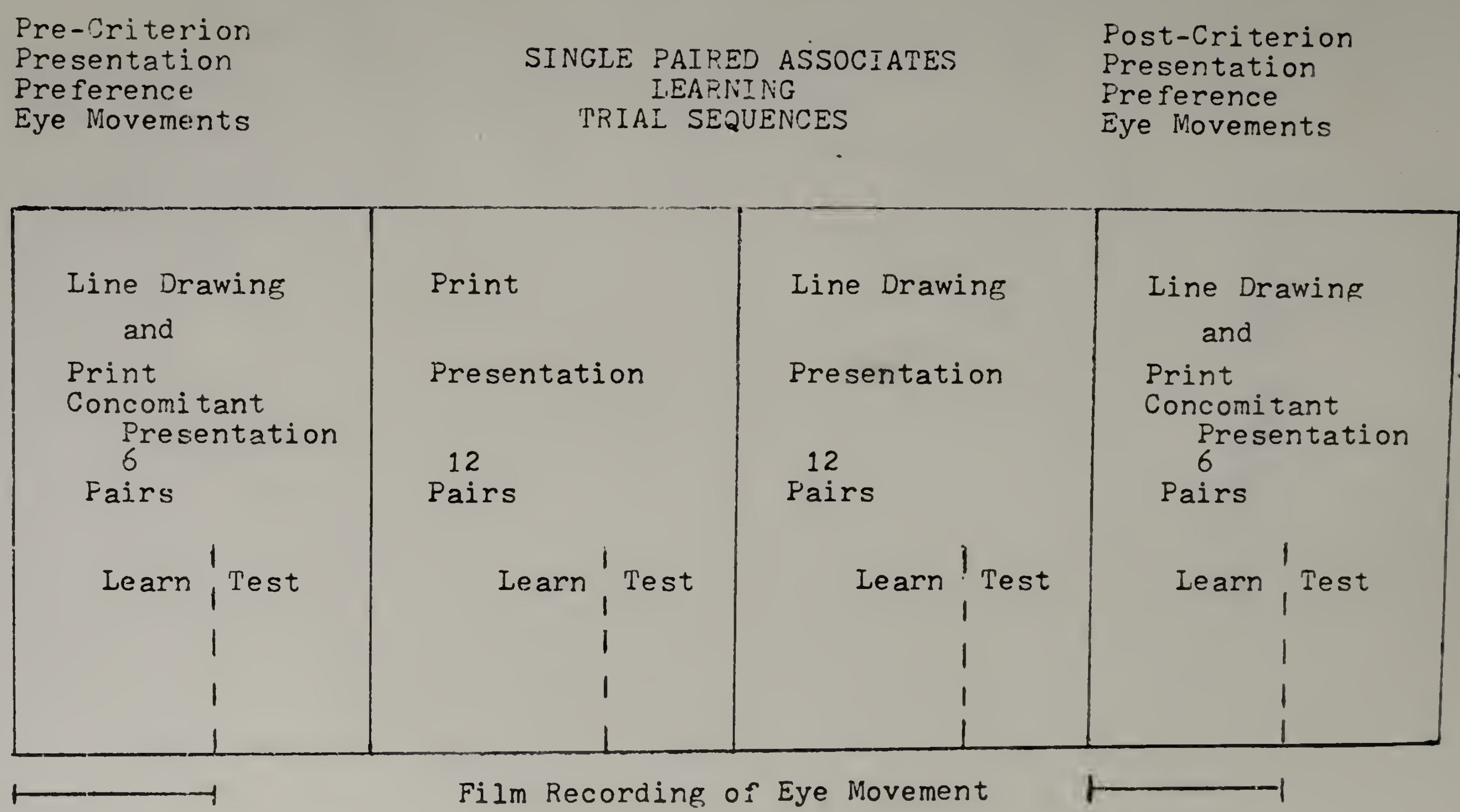
Pairs to Remember	SLIDE 74
The tractor smashes the mask	SLIDE 75
The stick strikes the rice.	SLIDE 76
The towel dries the plate.	SLIDE 77

The marble bumps the thump.	SLIDE 78
The swing nicks the bathtub.	SLIDE 79
The hammer pulls the bell.	SLIDE 80

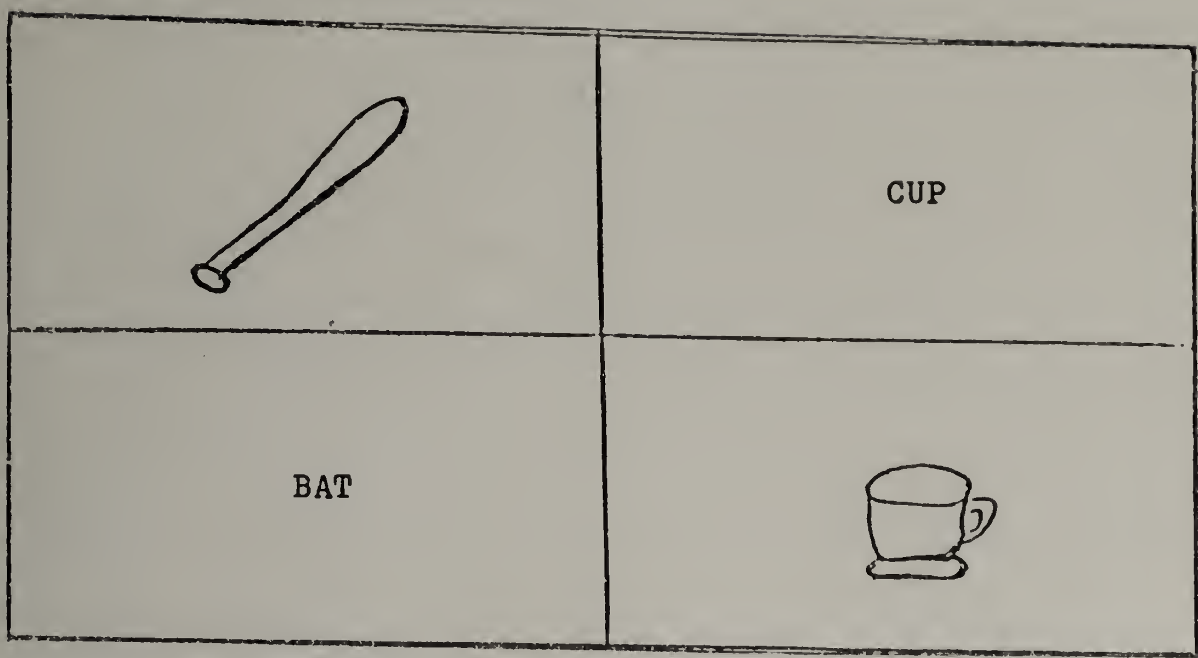
Now give your answers out loud.

TEST	SLIDE 81
Hammer	SLIDE 82
Towel	SLIDE 83
Marble	SLIDE 84
Stick	SLIDE 85
Swing	SLIDE 86
Tractor	SLIDE 87

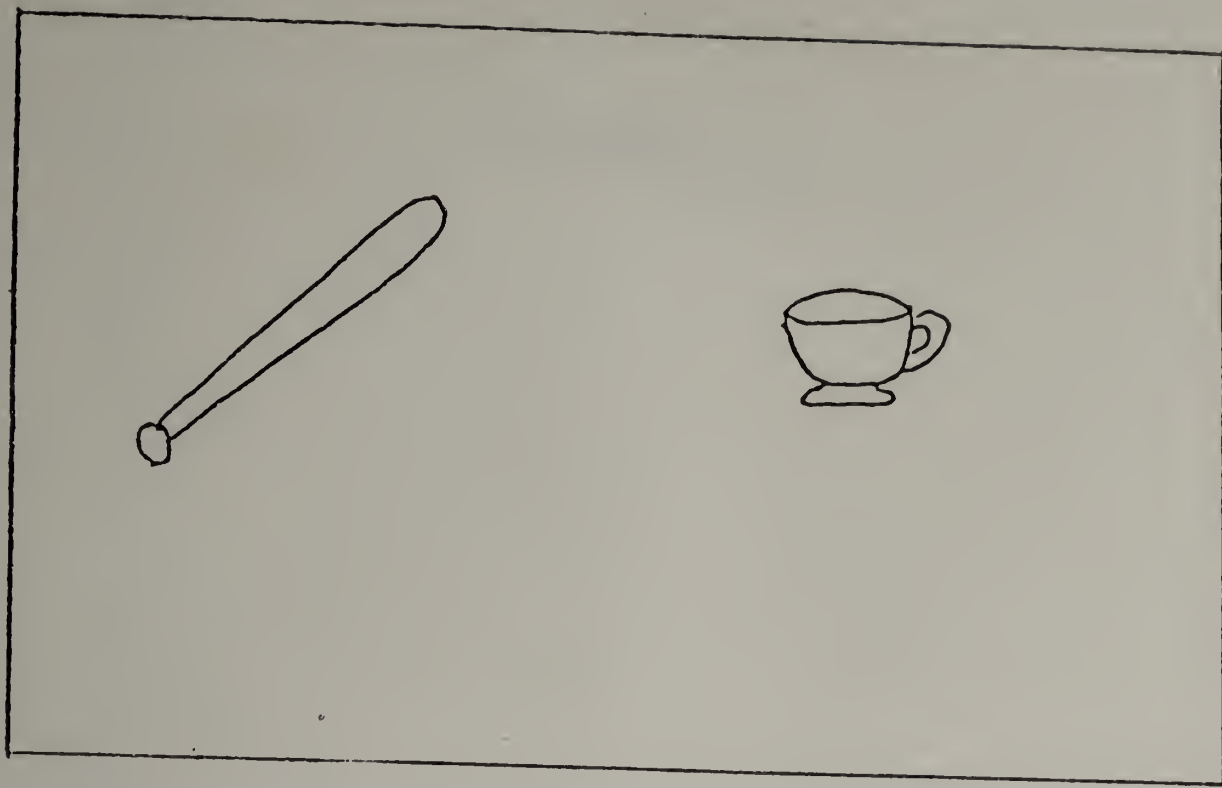
Thank you for helping us.

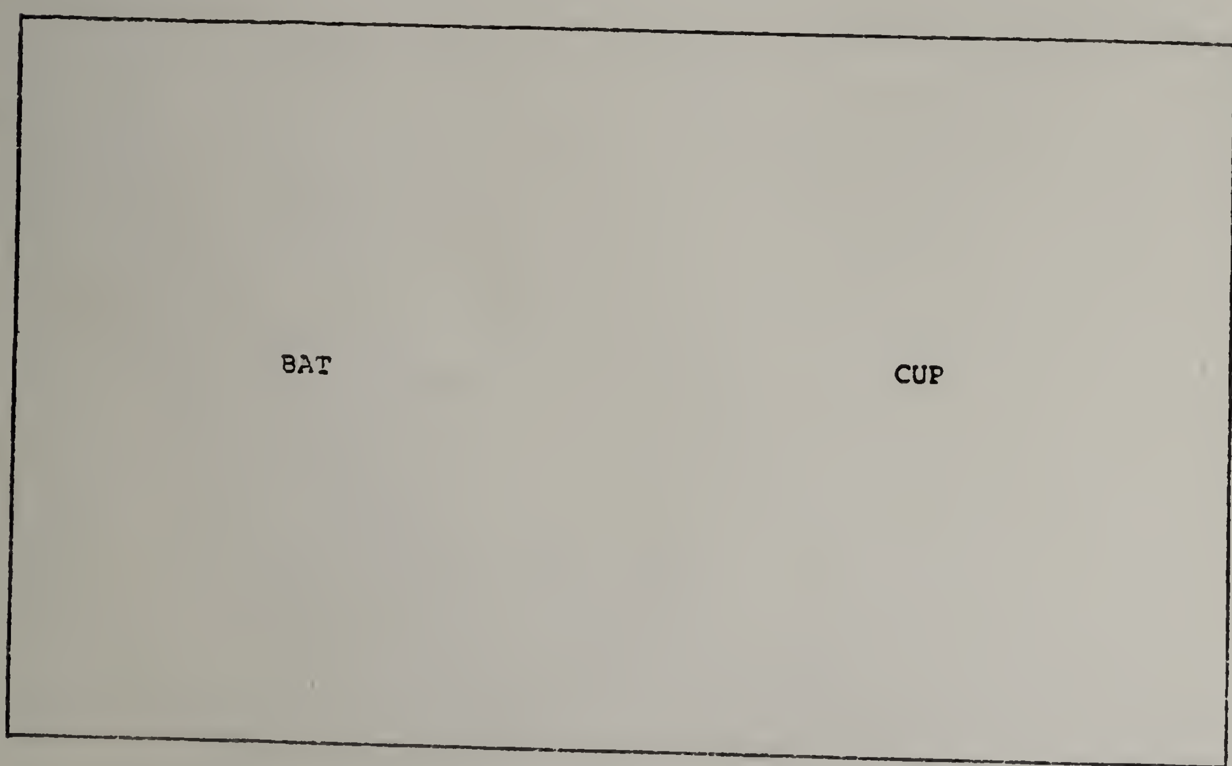


TREATMENT PROCEDURES



CONCOMMITANT PAIRED-ASSOCIATE LEARNING
VISUAL FRAME





PAIRED-ASSOCIATE LEARNING VISUAL FRAMES

APPENDIX IV

Letter to Parents

Below is a copy of the letter sent to the parents of a group of subjects, 8th grade students, requesting permission for their child to participate in the experiment.

Dear Parents:

Some of the eighth grade students from the Holy Family Grammar School will be asked if they wish to participate in a current research project. The title of the research project is: "The Design and Testing of a Portable Eye Movement Camera". The testing will be conducted as 123 Pine Street. Your child will be transported to and from home to the testing center. During the testing your child will be viewing a group of slides and listening to a synchronous sound track of the material. The subject matter will be based on an assortment of paired diagrams, such as, a ball a bat etc., developed by W. D. Rohwer.

It will take approximately one hour to complete the testing.

Sincerely yours,
s/ Robert A. Sasseville
Doctoral Candidate
University of Mass.

I hereby permit my child, ______________________________ to participate in the project: "The Design and Testing of a Portable Eye Movement Camera".

Date______________ (Signed)____________________

APPENDIX V

Equipment Design Questionnaire

Equipment Design

Eye Movement Equipment Questionnaire

Directions:

Please answer all questions to the best of your ability.

1. Name ____________________

2. Age ____________________
(years) (months)

3. Male ________ Female ________

In the following questions kindly check the appropriate column. a. excellent b. good c. fair d. poor

	a	b	c	d
4. How did you enjoy using the equipment?				
5. How did you like the material presented?				
6. How would you rate the use of the machine?				
ease of use				
comfort in use				
picture clearness				
sound				
quietness				
7. How would you enjoy using the machine for taking a test?				
8. How would you rate the directions given in the sound track?				
9. How would you rate having to give a spoken answer instead of a written answer?				

10. List (on the back of this paper) any reccommendations concerning improvements on the equipment used.

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BIBLIOGRAPHY

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