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ABSTRACT

Noting that the equipment traditionally used in eye movement research is both expensive and stationary in nature, this report describes apparatus for collecting and interpreting eye movement data that is both relatively inexpensive and portable. The report lists and describes hardware and software components of a data collection and data analysis system that provides precise information regarding the location, duration, and sequence of eye fixations during the reading of materials that are composed of both text and pictures. It also describes a procedure for collecting eye movement data in nonlaboratory settings, such as classrooms. (Author/FL)

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DEPARTMENT OF EDUCATION
College of Agriculture and Life Sciences
CORNELL UNIVERSITY

INSTRUMENTATION AND SOFTWARE FOR THE COLLECTION, ANALYSIS, AND INTERPRETATION OF EYE MOVEMENT DATA DURING READING

Rafael Hirschfeld
George Bieger

Technical Report No. 3

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Describes a method and apparatus for collecting and interpreting eye movement data, for research on reading pictures as well as text, that is both relatively inexpensive and portable. Lists and describes hardware and software components of a data collection and data analysis system which provides precise information regarding the location, duration, and sequence of eye fixations during the reading of materials that are composed of both text and pictures. Also describes a procedure for collecting eye-movement

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Abstract

Describes a method and apparatus for collecting and interpreting eye movement data, for research on reading pictures as well as text, that is both relatively inexpensive and portable. Lists and describes hardware and software components of a data collection and data analysis system which provides precise information regarding the location, duration, and sequence of eye fixations during the reading of materials that are composed of both text and pictures. Also describes a procedure for collecting eye-movement data in non-laboratory settings such as classrooms.

Instrumentation and Software for the Collection, Analysis, and Interpretation of Eye Movement Data during Reading

During the past few years investigators in several domains of cognitive psychology have begun to develop and use techniques for recording the patterns of small eye movements and "fixations" which they use as correlates of mental processes. In particular they have been studying fixation durations as indices of the temporal properties of mental operations, including those mental operations and processes involved in reading (Bouma & deVoogd, 1974; Carpenter & Just, 1972, 1977; Just & Carpenter, 1976a, 1976b, 1980; Lefton, 1978; Loftus, 1975; McConkie, 1976; Rayner, 1975a, 1975b, 1977, 1978; Rayner & McConkie, 1976). Although such techniques have proven valuable, they have been found to have at least two major practical drawbacks limiting their widespread use in reading research. The first obstacle has been the high cost. Eye tracking devices are typically expensive themselves and usually require very costly accessory equipment to be useful. An equipment expenditure in excess of $50,000 is not unusual, but is often prohibitive to many prospective researchers in this field. A second problem is that such equipment is necessarily stationary and requires that all data be collected in the laboratory. This limitation often precludes (or at least makes more difficult) the use of subjects who do not have easy access to the laboratory. Data from these subjects are often useful in those investigations concerned with individual differences in reading. This report describes apparatus and procedures designed to overcome these obstacles while retaining the precision and accuracy necessary for the use of eye movement techniques in reading research.

The development and use of the equipment, software, and procedures described below came about in response to problems encountered while investigating the ways readers use the information contained in materials consisting of pictures and text. Our intent was to manipulate the location of certain kinds of information (e.g. locative or descriptive information) in text or pictures and measure the effects of these manipulations on comprehension. We wanted to know what caused a reader to leave the text to search a picture for additional information and where in the picture they looked for that information. We also wanted to compare reading strategies among diverse categories of readers; for example, beginning and immature versus accomplished readers. These objectives required that we know: (a) where the reader was looking (i.e. the location of the eye fixation), (b) how long he/she attended to that location (i.e. the duration of the fixation), and (c) where he/she looked next (i.e. the sequence of fixations). Also, collecting data from people of various backgrounds, many of whom could not practically come to our laboratory, required a portable data collection system.

Given our budgetary limitations, we attempted to adapt our equipment to meet the specifications of our research. That equipment is described below and our laboratory layout is shown in Figure 1.

Insert Figure 1 about here.

Equipment

1) Gulf and Western Model 106 Eye-trac system (cost $2500) This device uses a differential reflection method of limbus and eyelid tracking, and produces an analog signal proportional to the displacement of the eye. Since it can follow each eye's movements in only one direction, we record horizontal movements from one eye and vertical movements from the other. It is equipped with a chin and temple rest and has been modified to include a head restraint to minimize head movements but allow reasonable comfort. The machine is easily portable and we have bolted it to a base which in turn can be clamped to any table or platform to provide it with stable support.

2) JVC KD-A2 stereo cassette deck (cost $300) We use this to store the output of the Eye-trac system

when we are away from the laboratory and cannot send the signal directly to the computer. In order to record the D.C. signal we have built a detachable modulator/demodulator (see Figure 2).

3) Data Translation DT2762 A/D converter (cost $750)
This takes the analog signal from the Eye-trac system or the tape deck and converts it to a digital value for computer analysis.

4) PDP-11/03 computer system (cost $4500)
The computer system includes a dual floppy disk drive, 32K RAM, 4-port serial line interface, line time clock, and CRT terminal. The system accepts data from the analog to digital converter and stores them on floppy disks for subsequent analysis. This analysis will be described more fully in the section on software.

5) Hewlett-Packard 7221B plotter (cost $5000 - optional)
Although this device is not essential, we have found it extremely useful for displaying eye positions and for setting up maps of the stimuli. The plotter sends the boundaries of all stimulus target regions to a mapping program (using a digitizing sight) and, after data have been collected, plots the eye positions over a larger scale reproduction of the stimulus.

Software

1) MAP - creates a map of target locations in the stimulus (i.e. words or parts of pictures) by acceptng the digitized coordinates of the boundaries of the target areas from the plotter. In configurations without the plotter a modified version of MAP will accept the manually measured coordinates from the keyboard. This information is stored for subsequent comparison to the raw eye movement data gathered by the program ITRAK.

2) ITRAK - gathers data from the eye track machine. Two types of data are collected: the raw eye position data which is sampled at the rate of 60/sec., and calibration data used to map the eye position data onto the stored representation of the stimulus created by MAP. Currently, we ask the subjects to look at the corners of the stimulus card to determine the coordinates of the card boundaries. This information is then used to compute a linear transformation that changes the scale of the raw data to that of the stored stimulus map. We have found, however, that this method presents several problems. First, it is difficult to tell exactly when the subject is looking at a corner of the card. Second, due to nonlinearities inherent in the eye track machine and the analog/digital converter, these coordinates often do not define a rectangle, but rather some bizzare

quadrilateral. In order to remedy the first problem, we are installing a pushbutton switch connected to the external trigger input of the A/D converter. The subject would then push this button when looking at the calibration point to begin conversion. This will provide a more precise value for each calibration point. To overcome the nonlinearity problem, we are developing a more general interpolation algorithm.

3) MATCH - takes the eye movement data (from ITRAK) and determines the target area to which each pair of coordinates is closest. It does this by applying the transformation computed in ITRAK to the converted data and comparing the coordinates to those of the target regions in the stimulus map created by MAP. It then produces a summary listing of these target areas on the terminal, in the order they were scanned, and with the time spent on each.

4) PLOT (Optional) - makes a scaled reproduction of the stimulus and plots the eye movements on this depiction. For ease of interpretation we plot the reproduction of the stimulus in black ink; eye positions are shown in red ink; and a sequence of numerals is plotted in green ink at intervals of 60 eye positions, which corresponds to one second of sampling.

Procedures

1) After turning off the room lights to minimize artifacts, the experimenter calibrates the Eye-trac system for the particular subject.

2) The subject looks at each of the calibration points in succession and the coordinates of each is stored, either on floppy disks via the A-D converter and micro-computer, or on the cassette tape for later conversion and storage on floppy disks.

3) The subject begins reading and the program ITRAK collects eye position data and stores them on a floppy disk. In 'out of laboratory data collection', the subject's eye positions are sent from the eye track device to the cassette tape recorder, and later, in the laboratory, are sent from the tape recorder to the micro-computer using ITRAK. The subject is instructed to look at several 'landmarks' on the stimulus both before beginning and after finishing reading the material. During data analysis the eyes' positions before and after reading, as recorded by the equipment, are compared. If the recorded location for the same landmark has not changed from start to finish, we assume that the eyes' positions as recorded are accurate for the entire sample. If however, there is a substantial difference (Just & Carpenter, 1980 suggest that 0.5

degrees visual angle constitutes a substantial difference) the subject's data are not useable.

4) After the data are collected and stored on floppy disks, the experimenter runs MATCH, which summarizes the location, duration, and sequence of the eyes' positions during reading (see Figure 3).

5) (Optional) The experimenter runs PLOT which reproduces a scaled enlargement of the stimulus and plots the eyes' positions on it. These are represented by points, connected by straight lines which indicate the sequence of fixations (see Figure 4).

Insert Figure 3 about here.

Insert Figure 4 about here.

Data Analysis

The data collected by ITRAK and displayed by MATCH and PLOT is in such a form that it can easily be analyzed to identify the location, duration, and sequence of eye fixations. Figure 3 depicts the output from MATCH and can be used by itself to identify these important variables. The locations identified in Figure 3 represent the defined target area to which a given eye position was closest and the durations are measured in 'ticks' or sixtieths of a second. The order from top to bottom shows the sequence of fixations. The principle disadvantage with using MATCH alone is that the eyes will frequently stop at or near the boundary between two target areas. Because the eyes are never literally 'fixed' (there are small irregular movements called tremors that occur when the eyes appear staionary) this may cause MATCH to show a series of very brief fixations alternating between the two target areas surrounding the point of focus. Such a disadvantage is not necessarily serious if the general location of a fixation is all that is needed, however if more precise information about the eyes' position is required this limitation could be a problem.

The use of the graphics plotter has overcome this limitation. The plotter displays a reproduction of the original stimulus and PLOT draws the eyes' positions over this depiction. Figure 4 shows a sample of the PLOT and graphics plotter output. Note especially that the eyes' positions are indicated with substantial precision. This plotter and the program PLOT, used together with MATCH, allows us to determine the location, duration, and sequence of eye fixations with considerable precision.

The equipment, software, and procedures described above have enabled us to make relatively precise observations of eye behavior during reading without the prohibitively high costs which typically characterize such systems. We are also able to make those observations wherever there is a room capable of being darkened and that has an electrical outlet and a table. We feel that this instrumentation and procedures will provide opportunities for research byinvestigators who do not have the funds to purchase more expensive equipment.

Note: FORTRAN IV source programs, for all of the user written software described in this paper, are available on request by contacting:

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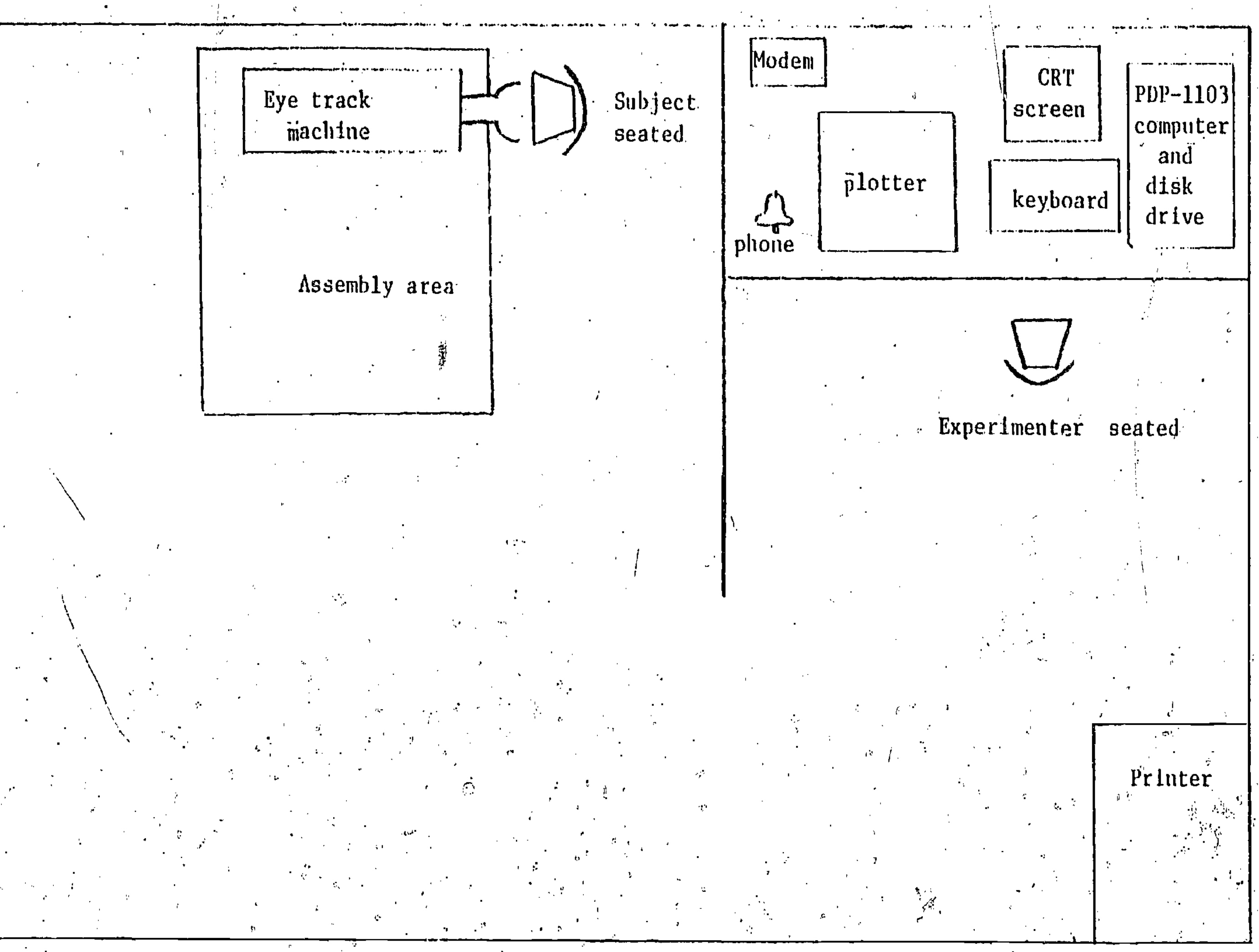


Figure 1. Eye movement laboratory

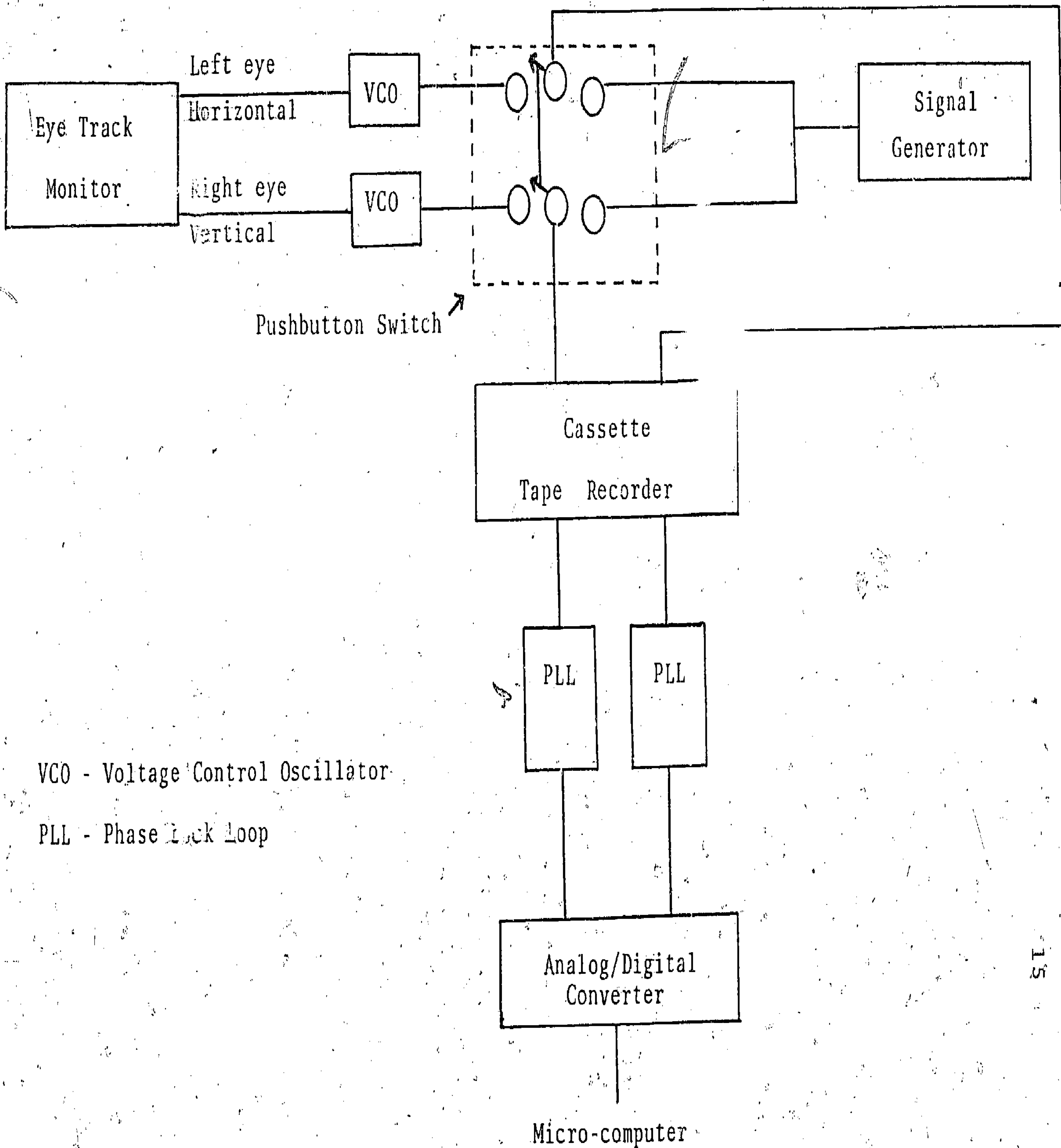


Figure 2. Schematic for modulator/demodulator device.

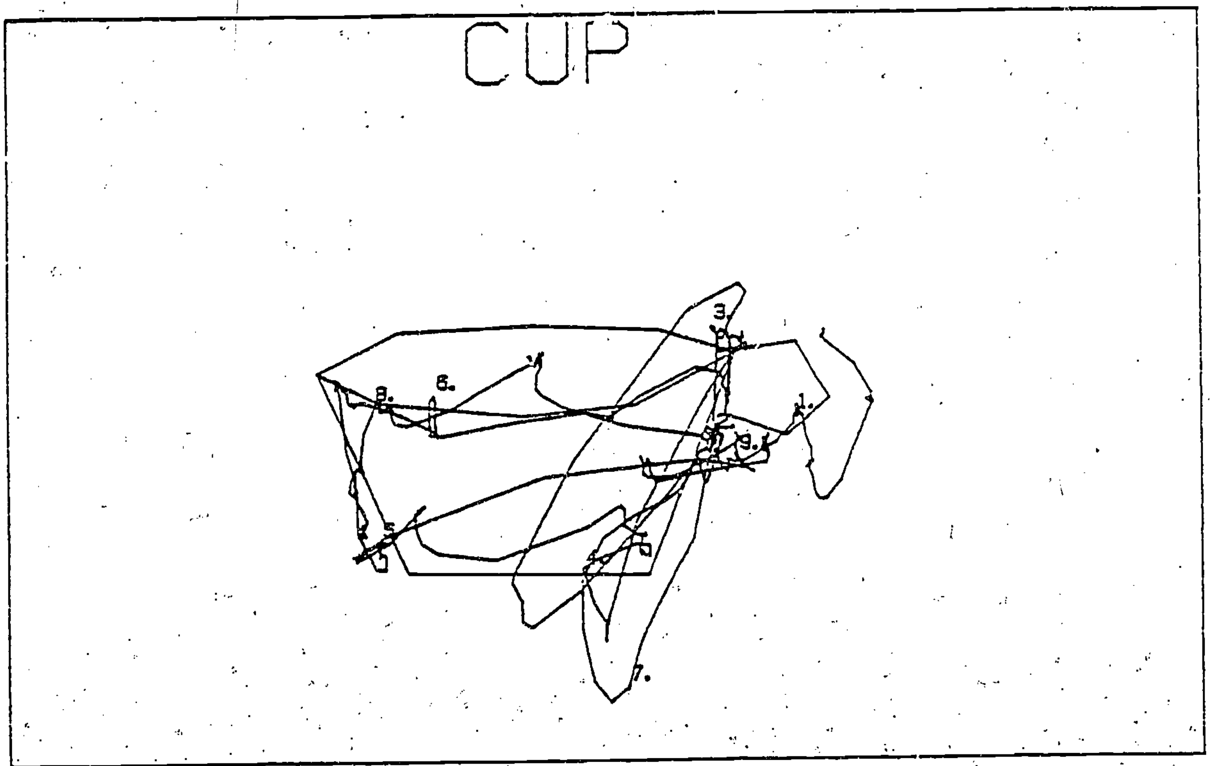
Duration is indicated in "ticks" each of which is 1/60th of a second (16.7 ms)

Location indicates the word to which the eye's focus was closest

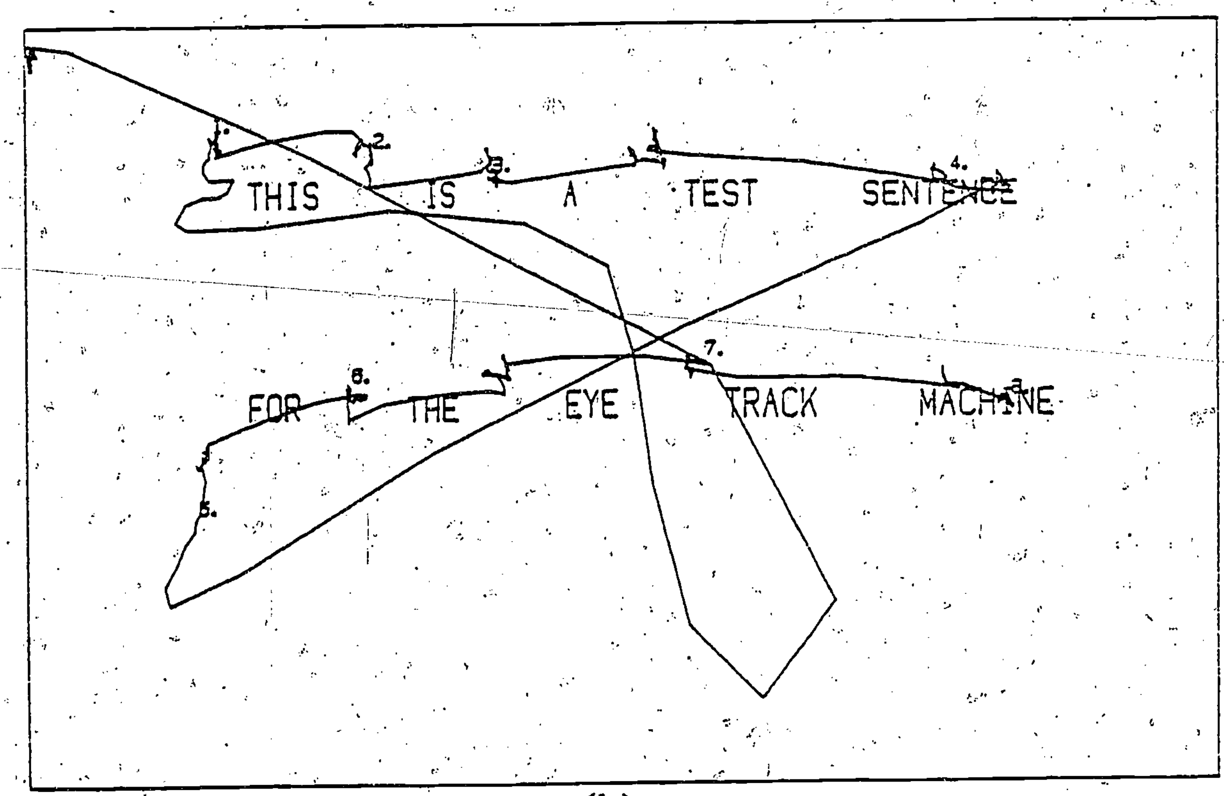
duration	location	
28	THIS	-- cluster of points in the upper left corner, at the beginning
4	TRACK	
4	EYE	
1	IS	-- eye blink
3	FOR	
93	THIS	-- fixations #1 and #2
50	IS	-- #3
2	A	
3	TEST	
5	A	-- fixation between "A" and "TEST"
44	TEST	
53	SENTENCE	-- #4
1	MACHINE	
1	TRACK	-- regressive sweep to beginning of second line
1	THE	
46	FOR	-- fixation above #5
7	THE	
31	FOR	-- #6
37	THE	-- between "THE" and "EYE"
2	EYE	
35	TRACK	-- #7
55	MACHINE	-- #8
1	TRACK	
1	THE	-- movement back toward the top for second reading
2	FOR	

Figure 3. Sample of output from MATCH program.

(To be used with Figure 4b)



(a)



(b)

Figure 4 Samples of output from PLOT program

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