

An eye movement analysis system (EMAS) for the identification of cognitive processes on figural tasks

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EMAS is a software system (written in VAX-11 FORTRAN) for the analysis of eye movement data recorded during the performance of figural tasks. Its main functions are: (1) Calibration of raw coordinates of eye movements to determine their actual position on the stimulus display. Different kinds of measurement distortion may be corrected. (2) Identification of eye fixations and the determination of their locations and durations. (3) Analysis of fixation sequences. The frequency of transitions of fixations among specified sectors of the stimulus display is computed. A sequential list is made of the successive fixations in which the fixated sector and the fixation duration are graphically indicated. (4) Plotting of raw or calibrated eye movement data and fixation points. The sequence of fixations in specified display sectors can also be plotted in real time. Applications of the programs to the Embedded Figures Test and the Hidden Figures Test are illustrated.

A recent approach to the study of intelligence focuses on the cognitive processes used by subjects to solve different types of test items (e.g., Sternberg & Detterman, 1979). Some researchers record eye movements during the solution of a cognitive task to identify processing stages or strategies (Carpenter & Just, 1978; Snow, 1980).

Generally, these tasks are rather complex, and the pattern of eye movements indicates a highly "arbitrary" selection of information. Therefore, most research is still concerned with some kind of exploratory data analysis (Tukey, 1977), aiming at the identification of structural aspects of the solution process.

In a research project (Groot, 1984), a software system has been developed that can be used for the analysis of eye movements in cognitive tasks in which figural information has to be processed.

COMPUTER CONFIGURATION AND SOFTWARE SYSTEM

A VAX-11/780 computer with the VMS operating system is used. The set of programs is written in VAX-11 FORTRAN; two of these programs are designed for making plots on a ZETA plotter (Release 53).

Functions of the Programs

Besides programs for the usual stages of analysis of eye movements, specific programs for the analysis of

task-related aspects of the eye movements are included. Figure 1 shows a flow diagram of the system. The main functions are: (1) Calibration—The horizontal and vertical coordinates of the eye view monitor (EVM) output

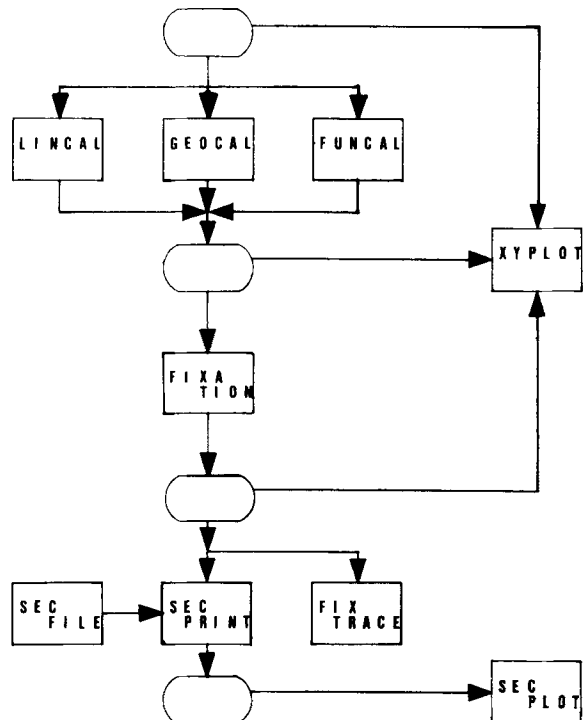


Figure 1. System flowchart of the eye movement analysis system. Cylinders indicate files on mass storage. Rectangles indicate programs that can be run. Arrows indicate the order in which programs are run and which output files can be input files to subsequent programs.

We wish to thank Ad Marien for contributing to GEOCAL and FUNCAL and Frans Hummelman for contributing to FIXA-TION and XY PLOT, and Piet Giesbers, Paul Vermaseren, and Ed van den Bosch for providing system support. The authors' mailing address is: Department of Psychology, Tilburg University, P.O. Box 90153, 5000 LE Tilburg, The Netherlands.

can be transformed into the real coordinates of the eye movements on the stimulus display. Different programs (LINCAL, GEOCAL, or FUNCAL) can be used, depending on the kind of distortion in the measurement of the eye position that has to be corrected. (2) Calculation of eye fixations—The program FIXATION detects fixations and determines their locations and durations. (3) Determination of sequences of fixations within or between specified sectors of the stimulus display. Different programs (FIXTRACE, SECFILE, SECPRINT) can be used. (4) Plotting—The output of most programs can be plotted by using the programs XYPLOT and SECPLLOT. A description of each of these programs is provided below. All programs are designed for off-line use and are independent of the original file. The most characteristic feature of EMAS compared with other programs (e.g., Kliegl & Olson, 1981; McConkie, 1981) is that it offers facilities for descriptive analysis of eye movement patterns on relatively complex problem-solving tasks with figural information.

Input and Output

Inputs to the system are A/D (Analog/Digital) converted sequential files containing eye movement coordinates measured by an EVM of Gulf+Western Applied Science Laboratories (Model 1998S) and an optional sequential file containing coordinates of the outlines of figures on the stimulus display. When the different programs are run, several output files are created. Some of these may be used as input files for further analysis programs in the system. Other output files can be printed or plotted.

Calibration Programs

When eye movements are measured, their numerical horizontal and vertical coordinates generally do not indicate eye position on the display. The calibration programs transform the eye movement coordinates in the original file into the units in which the stimulus display has been scaled. LINCAL is used when it is not necessary to correct for measurement distortion. After an on-line computerized calibration procedure had been implemented, only LINCAL needed to be used. Eye movement data gathered previously with manual calibration required further off-line correction for measurement distortion. For that purpose, the programs GEOCAL and FUNCAL were developed.

LINCAL. This program linearly transforms the EVM coordinates into the coordinates of the stimulus display. The input consists of a file with raw EVM coordinates and an optional file containing coordinates of the outlines of the figures in the display. The intercept and slope of the transformation function are computed after the user has provided a table with two EVM values and their matched display values (horizontal and vertical axes). These values can be obtained by recording the values of the calibration points used in the standard EVM calibration procedure. The output of the program is a

file containing calibrated coordinates. A scatter diagram of the calibrated sample points is shown on the monitor. When coordinates of the outlines of the figures seen are available, they are superimposed on the data. The information on the monitor can be printed.

GEOCAL. GEOCAL can correct distortions in the measurement of eye position. A linear interpolation method is used (McConkie, 1981). Up to four regions of the stimulus display can be selected if transformation parameters differ for these regions. The same input files are used as in LINCAL. The user should provide a table with the EVM coordinates of four, six, or nine positions and their matched display coordinates, depending on the number of regions selected. As in LINCAL, a calibrated file and a file containing the scatter diagram on the monitor are obtained. In our research, this program appeared useful for calibrating individual data files with apparently unsystematic distortion. In such a case, data points in the file with known display coordinates were selected as calibration points.

FUNCAL. FUNCAL uses a transformation function to correct EVM coordinates as proposed by Sheena and Borah (1981). The horizontal and vertical eye position (EPH, EPV) on the display are calculated by the following functions:

$$EPH = a + b * X + c * X * X + d * Y + e * Y * Y + f * X * Y$$

$$EPV = a + b * Y + c * Y * Y + d * X + e * X * X + f * X * Y$$

These functions especially correct "crosstalk" and distortions in the corners of the display. The same input files are used as in the previous calibration programs. A calibration table with 6 to 15 EVM point values and their matched display values should be given in order to enable the program to compute the transformation coefficients. If more than six values are given, a least squares criterion is used to obtain optimal coefficients. The output is analogous to the previous calibration program. We routinely use FUNCAL to calibrate off-line data recorded by an Applied Science apparatus with a manual calibration procedure.

Program for Calculating Fixations

FIXATION. FIXATION identifies eye fixations in calibrated or uncalibrated eye movement data. The algorithm detects clusters of successive sample points of the eye movement data. When a specified distance between the mean of the coordinates in the current cluster and the next sample point is exceeded, clustering stops and the current cluster is classified as a fixation, unless the number of sample points in the current cluster is below a specified minimum; in that case, the cluster is classified as a saccade. Optionally, the program continues clustering when one outlying sample point has been detected between acceptable sample points. Input is a file containing calibrated or uncalibrated coordinates and an

optional file containing coordinates of the outlines of the figures in the display. Output is a file containing a scatter diagram of the fixation points on the stimulus display, a list of the fixation points, saccades and out-of-display points, and statistical information about the duration of the fixations, their frequency distribution, the quartiles, and the interquartile range. Blinks are identified as out-of-display points. Their location and percentage of the sample points are indicated in the output list.

Programs for the Analysis of Eye Fixation Sequences

Three programs have been developed for the representation of eye fixation sequences at two different levels of analysis.

FIXTRACE. FIXTRACE prints sequences of individual fixations on the stimulus display. It is particularly useful for the representation of eye fixation sequences on visual tasks with an unstructured visual field and on visual tasks in which the subject scans lines with many symbols or small figures, as in most perceptual speed tasks. Input is a file containing fixation points and an optional file containing markers of the figures in the display. The output is a printed two-dimensional grid of the stimulus display in which the successive fixations are indicated by their rank number. Also, in the output a list is given of the fixations, their grid coordinates, and their rank number. Fixations with the same grid coordinates get the rank number of the first fixation on this position.

SECFILE. SECFILE is used to define different sectors of the stimulus display that contain different sources of information presumably relevant to the performance of the task. The program aggregates small rectangles that make up the relevant display sectors. Each sector gets a code that is used as reference in the other programs. If necessary, subsectors can be distinguished. With this method, sectors with different shapes can be defined. Input is a file name with a set of sector codes together with their horizontal and vertical ranges. The output is a file that can be used in the program SECPrint to allocate fixations to the appropriate sector.

SECPrint. This program allocates fixation points to relevant sectors and prints a sequential plot of successive fixations. Each sector is represented by a column. The duration of each fixation is indicated by the length of the appropriate bar. The output also contains matrices with the frequencies of transitions between fixation points within and between the specified sectors. Furthermore, a file is made to obtain a graphical plot of the successive fixations in different sectors using the program SECPLOT.

Programs for Plotting Eye Movement Data

Graphical plots are very useful representations for an exploratory analysis of eye movement data. In EMAS, two plot programs can be used. Both are written for use on a ZETA plotter (Release 53).

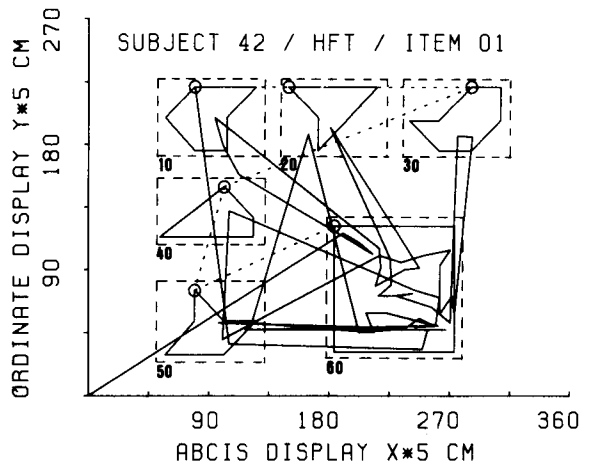


Figure 2. Output example of the program XYPLOT. The plot gives fixations of Subject 42 during the solution of an item on the Hidden Figures Test. Plotted are the fixations, the outlines of the figures at which the subject looked, and the sectors (dashed rectangles) to which fixations are subsequently allocated by the program SECPrint.

XYPLOT. XYPLOT can be used to plot raw or calibrated coordinates of eye movements or fixation points in an xy-plot. Outlines of figures on the display looked at by the subject may also be included in the plot. The program starts with reading in the x and y values. Every point within the ranges is plotted. When a point is outside the ranges, a circle is plotted around the previous point and a dashed line is plotted to the next point within the display. Input is a file with uncalibrated or calibrated data or fixation points. An optional file containing markers of the figures in the display may be added. Output is a plot on the ZETA plotter.

Figure 2 shows an output example of the program XYPLOT. Inputs to the program were a file with fixation points of Subject 42 and a file with outlines of the stimulus display of an item of the Hidden Figures Test (HFT). Figure 2 shows the performance of Subject 42 during the solution of an item of the HFT. The track starts at the lower left of the plot. The sectors used in SECPrint are indicated by dashed rectangles.

SECPLOT. SECPLOT makes a sequential plot of successive fixations in different sectors of the stimulus display. It is a graphical representation of the output of SECPrint. The abscissa (time) of this plot is variable and depends on the duration of the solution period. The ordinate represents selected sectors. Input to the program is the output file of SECPrint. Output is a plot on the ZETA plotter.

APPLICATIONS OF THE PROGRAMS SECPrint AND SECPLOT

To demonstrate how EMAS can be used for an exploratory analysis of eye movements recorded during the performance of figural tasks, some applications of

the programs SECPRINT and SEC PLOT are shown and discussed. These programs were used for the analysis of eye fixation sequences during the solution of an item of two different tests of the cognitive style field dependence/independence: the Embedded Figures Test (EFT) of Witkin, Oltman, Raskin, and Karp (1971) and the Hidden Figures Test (HFT) of French, Ekstrom, and Price (1963). In the EFT, a simple figure has to be detected within a complex figure. The simple figure is presented during the 10 sec prior to the presentation of the complex figure. On the HFT, five simple figures are presented simultaneously with a complex figure in which one of the simple figures is hidden. In the theory of field dependence/independence, it is hypothesized that a field-dependent individual predominantly uses a "global" strategy; that is, unarticulated, unstructured encodings or internal representations of information are made in solving problems. A field-independent individual is characterized by an "analytic" strategy. To illustrate these strategies on the EFT, the sequence of eye fixations on different sectors of a simple figure of an EFT item was determined using the program SECPRINT. Figure 3a shows the simple figure and the sectors. Figures 3b, 3c, and 3d have been derived from the output of SECPRINT and present the sequences of fixations

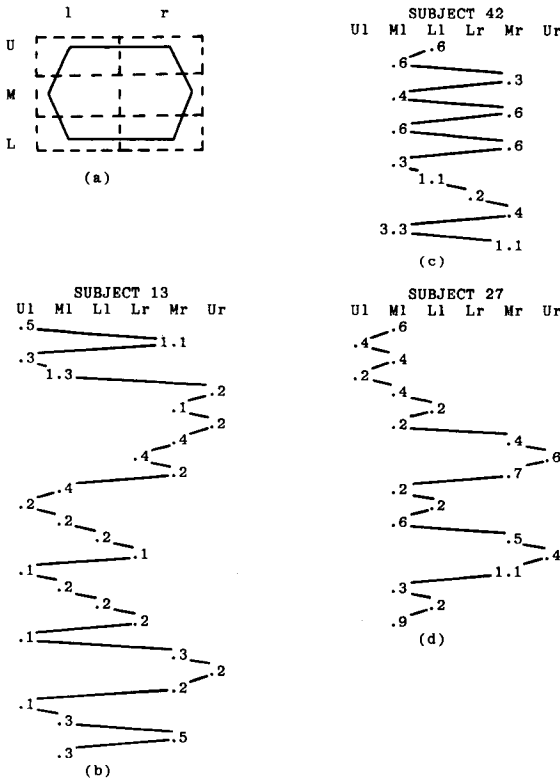


Figure 3. (a): A simple figure of an Embedded Figures Test (EFT) item divided into different sectors (U = upper, M = middle, L = lower, l = left, r = right). (b), (c), and (d): Eye movement sequences for three subjects on sectors of a simple figure of an EFT item. Time runs from top down in each figure. Numbers indicate gaze pauses in seconds.

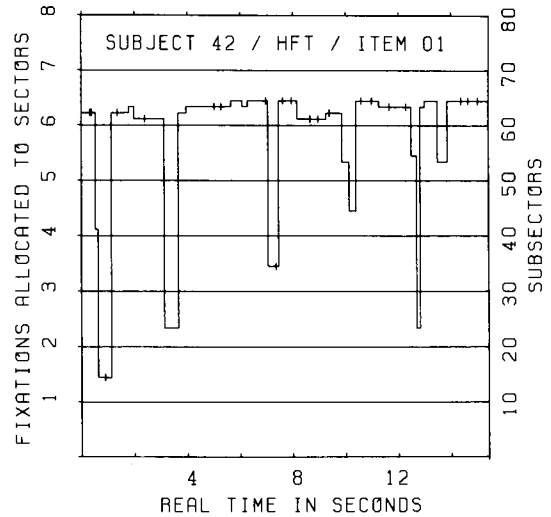


Figure 4. Plots of successive fixations of Subject 42 in different sectors of a Hidden Figures Test item shown in Figure 2. The zones 1 to 5 represent sectors 10 to 50, each with a simple figure, and zone 6 represents sector 60 with the complex figure. Each horizontal line segment of the track indicates a single eye fixation of a defined duration. Line segments on different levels within a zone indicate fixations on different subsectors.

and their durations in different sectors of the simple figure for three subjects. Subjects 42 (Figure 3c) and 27 (Figure 3d) obtained high total scores on the test, and Subject 13 (Figure 3b), a low score. Subject 42 gazes systematically and for relatively prolonged periods at a few selected sectors. Subject 27 also scans systematically, but fixates on more sectors, whereas Subject 13 rather unsystematically scans with many short fixations nearly all sectors. The encoding of the simple figure as done by Subjects 42 and 27 can be qualified as analytic or "articulated," and that by Subject 13 as global or "unarticulated." To illustrate strategies on the HFT, the stimulus display of the HFT item has been divided into sectors and subsectors. Figure 2 shows these sectors, indicated by dashed rectangles. The output of the program SEC PLOT, consisting of the eye movements of Subjects 42, 27, and 13, is presented in Figures 4, 5, and 6, respectively. A plot gives the sector location and the duration of successive fixations in the first 15 sec of the solution period. The lengths of the horizontal line segments are proportional to the durations of the fixations. Ordinate zones 1 to 5 represent the five sectors with the simple figures, and zone 6 represents the sector with the complex figure. Fixations outside those sectors are located below zone 1.

The patterns of the fixations of the subjects are different. Subject 42 makes only one comparison between a simple figure and the complex figure and then systematically proceeds to the next simple figure. Subject 27 searches exhaustively each simple figure in the complex figure and then systematically proceeds to the next simple figure. This cannot be shown completely in the plot, because only the first 15 sec are included. Subject 13 does not systematically organize the search periods for

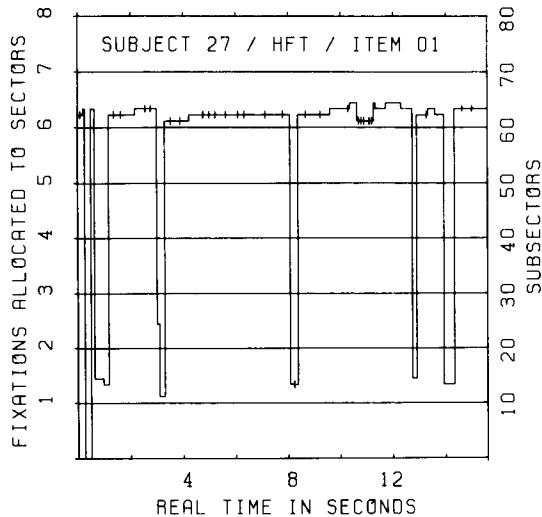


Figure 5. Plots of successive fixations of Subject 27 in different sectors of a Hidden Figures Test item shown in Figure 2. Zones 1 to 5 represent sectors 10 to 50, each with a simple figure, and zone 6 represents sector 60 with the complex figure. Each horizontal line segment of the track indicates a single eye fixation of a defined duration. Line segments on different levels within a zone indicate fixations on different subsectors.

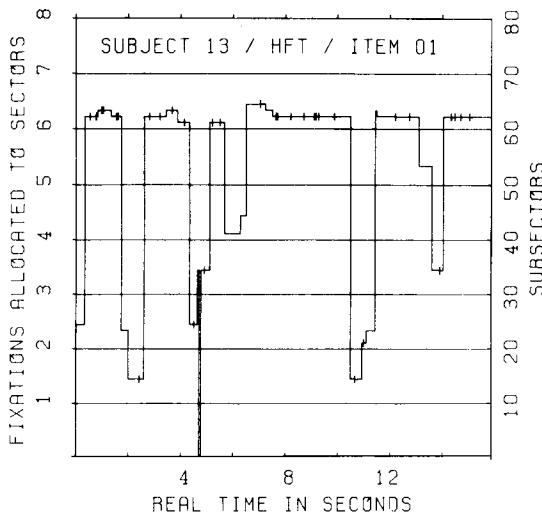


Figure 6. Plots of successive fixations of Subject 13 in different sectors of a Hidden Figures Test item shown in Figure 2. Zones 1 to 5 represent sectors 10 to 50, each with a simple figure, and zone 6 represents sector 60 with the complex figure. Each horizontal line segment of the track indicates a single eye fixation of a defined duration. Line segments on different levels within a zone indicate fixations on different subsectors.

a single simple figure: Different simple figures are fixated before he starts searching in the complex figure, and some simple figures still are ignored while earlier comparisons are repeated.

When the eye movement data on the two tests are compared for the three subjects, some consistency is apparent. Subjects 42 and 27 show a more systematic and elaborate encoding and comparison of the figural

information than does Subject 13. This difference in the solution process can be described, respectively, as the use of an analytic and a global strategy. But are these strategies independent determinants of task performance? They may be conceived of as epiphenomena of actual determinants. In our project, the later interpretation of differences in strategy is preferred. Their relationships with individual differences in motivational state in the test situation and with type of advanced education have been reported previously (Groot, 1981).

SYSTEM EXTENSIONS

For each program there is a command procedure that, together with a set of test data and a program for exploding the test data, can be used to demonstrate how to work with the programs and to test several different values that the parameters and data may have.

AVAILABILITY

Source listings of the individual programs, a user guide, and command files can be obtained (only tape or floppy costs will be charged) from C. J. Groot, Department of Psychology, Tilburg University, P. O. 90153, 5000 LE Tilburg, The Netherlands.

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