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Human processing of computer-controled displays.

Final Report

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Abstract and Recommendations

Movements of the eyes were recorded and analyzed as people read texts presented in 2 different spacings, 2 different character densities, and at 5 different scrolling rates. The two spacings, single and double, induced statistically different results in efficiency of reading, but at a quantitative level of little practical significance. Character density was evaluated by presenting 4Ø characters or 8Ø characters per line (actually, 35 characters or 7Ø characters in the 4Ø or 8Ø size). Results favour the smaller size character in respect to efficiency of reading. Comparison of scrolling rates, from zero to a speed 2Ø% faster than the readers' judged optimum, suggests that the static page (zero rate) is processed more efficiently than the page the readers selected as an optimum rate or a page 1Ø% slower than their optimum; pages presented faster than their optimum were read more efficiently. The reason for these results seems to be that readers underestimate their "optimum". Moreover, little if any change in optimum occurs as a function of practice with 16 pages of text. An alternative, in which by program control text was presented at 1Ø%

or 20% faster than at the selected optimum scrolling rate, should lead to more efficient performance, but might create some problems of user acceptability. Our recommendations are as follows:

1. Single spacing should be used in preference to double spacing.

2. An 80-character line should be used in preference to a 40-character line.

3. Decisions regarding scrolling can be taken on economic or practical considerations other than those related to performance. If scrolling can be built in at little additional cost, it might be offered as an option to people who like to use it; but if it is costly to achieve, its implementation might not be wholly justified by behavioural criteria.

4. If scrolling is offered as an option, it should be smooth scrolling not jump scrolling.

Human Processing of Computer-Controled Displays

It seems highly likely that the CRT will become a standard medium for display of textual and graphic information, both in a passive mode, as on commercial TV, and in an interactive mode, as in Telidon. The CRT, or TV "page", offers several methods for presenting text, some of them unknown or impossible to the printed page. The recent development of interest in the CRT for such display purposes has concentrated primarily on its engineering aspects; hence the human factors or psychological aspect of performance has not been well studied. Moreover, where interest has been directed to the readability or interpretability of CRT faces, the principal measure of performance has been identifiability or discriminability of individual characters, preference ratings, or simply speed of reading. The method we use investigates performance in a dynamic way by assessing ocular and cognitive efficiency in the uptake of information from the display.

Considerable good work has been carried out on television legibility, needless to say, as in the well known studies of Shurtleff (1967, 1969), Vartabedian (1971), Giddings (1972), and others. More recently, investigators have directed their attention to the legibility of characters as determined by components of their dot matrix, as in the studies of Snyder and Taylor (1979) or

Riley and Barbato (1978). Discriminability studies suffer, however, from the intrinsic disadvantage of questionable predictabiliity to the dynamic situation; clarity and discriminability of individual characters is only a component--and one of uncertain significance--in overall reading. Classical studies (Huey, 1908) demonstrated empirically what everyone's experience also reveals. We can often read and understand quite well text whose individual characters have been made unrecognizable by smudges, distortions, and other perturbations of the display. Hence, readability or even legibility of a text cannot always be predicted accurately from confusion matricies or discriminability tests of individual letters.

A more dynamic procedure would assess actual performance. Until recently, the principal way to do this was to follow the standard technique (Tinker, 1963) of measuring speed of reading or time on task for different sorts of display, assuming or testing for equivalence of comprehension. With this method, almost all information regarding perceptual constituents of the task is lost and only the total time spent on the task is available as data. A method that promises more analytical data regarding performance measures the movement of their eyes as people read (Levy-Schoen & O'Regan, 1979). In the application we have made, a laboratory computer controls the display of a text on a television monitor; a specially adapted television camera records the eye as the subject reads the display, and suitable circuitry analyzes the TV output in terms of direction of gaze. The resulting data, sampled at 60 hz, are then stored by the same computer for subsequent analysis. We adapted this system to study the performance of people reading texts presented at varied rates, character densities, and spacing, with particular interest directed at the variable of scrolling. Our results suggest that scrolling confers a slight disadvantage to the reader compared to the static page when the reader sets the scrolling rate, for readers tend to underestimate their ability to read and understand.

Method

Apparatus. A PDP 11/Ø3 laboratory computer controled the display and recorded the data from the eye tracker. That device, a Whittaker (now Gulf + Western Applied Science Laboratories) Eye Movement Monitor uses an infra-red-sensitive television camera to acquire a highly magnified image of the reader's left eye, and calculates the position of the center of its pupil 6Ø times per second. Voltages put out by the circuitry vary with changes in the position of the eye in orbit. Interpretation of these voltages is made possible by comparing them to voltages generated when the eye looks at targets placed at known positions in space, the calibration target described below. The displays the person looked at appeared on an Electrohome 23-inch home television monitor that was slaved to a VT-1ØØ CRT terminal used as a character generator. Hence the character set was displayed interlaced, simulating the appearance of displays on the home TV.

In summary, the computer created a display for the person to look at while the eye movement monitor recorded variations in looking, and the digitized samples from the eye movement monitor were transmitted to the computer for processing. A schematic chart of the system appears in Figure 1. More detail regarding its operation is presented in Appendix 1.

Displays. The displays compared two text densities (4Ø and 8Ø character), two spacings (single and double), and five scrolling rates. One rate was zero scrolling, a solid page of text. The other four were individually tailored to each person's preferred rate and consisted of a rate 1Ø% slower than the preferred rate, the preferred rate, and rates 1Ø% and 2Ø% faster. Two kinds of scrolling were studied. One, the standard "jump scroll", moved the available text upward seemingly in a quantal jump from line to line. The other, a smoother-looking scroll, moves a whole line of text upward over a period of a considerable fraction of a second. In one case the text moves discretely and in the other it moves continuously. In preliminary experiments we found that jump scrolling induced many errors of reading and was uniformly disliked by the people tested; therefore the smoother scroll was substituted and all of the results below were obtained with that interlaced smooth scroll. The smoother scrolling is accomplished by moving the information in each raster line one raster line upwards every sixtieth of a second (the scrolling mode of the VT-1ØØ). As this traverse time is the same for all scrolling rates, differencies in scrolling rate were created by the amount of time a line of text was at rest before being moved.

Texts. Unrelated passages of about 3ØØ words in length were sampled from Miller (1962), a source used previously (Kolers, 1979) and known for the evenness of its style and its ready comprehensibility by an "educated layman." Examples of the text as it appeared on the screen can be found in Figures 2a to 2d. Each passage was followed by a set of 1Ø questions in order to insure that the subject actually read the various texts. These tests of comprehension were made up of questions half of which were and half of which were not answerable on the basis of the information in the passage just read. The subject indicated by tapping a key whether a question was answerable or not. Some samples of question pages appropriate to the texts of Figure 2 appear in Figure 3. Note, however, that the samples in Figure 2 do not illustrate a whole passage of 3ØØ words.

The texts appeared on a screen approximately 12Ø cm (4 ft) from the subject's eye. The effective field of the screen measured 38 x 28 cm, or approximately 17.5 x 13 deg visual angle. The letter M, the usual standard, measured 5 and 1Ø mm in width, or .25 and .5 deg visual angle at the eye, and 1Ø mm high, in the two character sizes. The length of the line used in practice was 35 or 7Ø characters.

Procedure. The data were collected over three testing sessions. In the first session the subject was familiarized with the apparatus, displays, and procedures. In addition, measurements of the preferred scrolling rate were made for each of the displays used.

Actual data were obtained in the second and third sessions. These consisted of eye movement records and comprehension test scores for each of the displays used. A typical session began with a set of calibrations; then five passages of text were presented for reading, each passage followed by a comprehension test. A second calibration ended this phase. After a rest of five to ten minutes, the procedure was repeated with another set of five passages. The session lasted about an hour, for a total of 1Ø passages and 4 calibrations. On the third day, the first phase was increased to six passages and the second phase was terminated by measurement of preferred scrolling rate again. As mentioned, the system measured movements of the reader's left eye. In order to improve accuracy of measurement, the reader wore an eye patch over the right eye. In addition, the reader's head was restrained by means of a chin rest and head clamp.

The order of presentation of the 2Ø texts was based on 2Ø random orders, thereby controling statistically against practice and fatigue. In the experiment subjects signalled by tapping a key to show when they had finished reading the scrolled page, or when they had finished an intermediate page of static text.

Calibration. Because of variations in geometry of individual eyes, direction of the eye's gaze cannot readily be determined from the data that the TV camera supplied if the data are referenced to absolute positions in space. An alternate procedure is to have the person look at specified targets and to measure the actual voltage signals generated by the TV camera for the eye at that position. If a large enough number of specified targets is employed, a fairly good representation of the eye's positions can be obtained from interpolated values. In practice, we used a 5 x 5 matrix of points which appeared individually on the screen for 1.8 sec each which the subject was instructed to look at directly. The 25 points defined the perimeter of the display space and interior points. Voltages generated by a subject's looks at the 25 targets were used to construct a two-dimensional surface based on least-squares fits of the points, and all other recorded voltages were interpreted in terms of this surface. This calibration procedure was repeated a number of times. The analyses reported here, however, concentrate on frequency and duration of fixations, not their location.

Subjects. The data reported are based on tests completed on 20 subjects. All were students, principally at the University of Toronto. All reported having normal visual acuity without corrective lenses. One subject claimed to have tunnel vision with only 5 deg of central vision. We tested her as a matter of interest but found her data indistinguishable from those of the other, normally sighted, subjects and so included it here. Another 10 subjects were excused after the second session or were replaced after the third because of poor or inadequate data due to enlarged pupils, excessive movements of the head, or the like. All subjects were volunteers recruited through public announcements and were paid for their participation. They were tested individually at about the same hour on each of three days.

Analysis. The Eye Movement Monitor generated 60 sample voltages per second for each of the three variables--vertical and horizontal components of eye position and pupil diameter. The latter variable indexes luminance changes to the eye, due principally to blinking, and affective reactions to the text. Since the text is fairly straightforward informative discourse, we are not in a position to interpret variations in pupil diameter. Hence, this variable was largely ignored in what follows. Special programs were written to evaluate the x and y outputs of the system. These discriminated steady fixations from movements of the eye, blinks, and other perturbations of the record. The overall logic of the software is described in Appendix 2. Data analysis was carried out upon the identified fixations of the eye, taking into account their number and duration and using these as input to appropriate analyses of variance. The analyses were usually 2 x 2 x 5 x 20 for spacing, character size, scrolling rate, and subjects.

Measures of the eye. Ocular behaviour can be decomposed into a large number of variables (Rayner, 1978) which serve different analytical functions, and many of which are correlated. The main analyses we have used are defined as follows:

1. Total number of fixations (NUMFIX). The total number of fixations required to read a single passage. Some fixations were lost due to system noise (including the subject), so the value was obtained by normalization, in order to make comparison across passages possible. The normalization yielded $N' = N \times T / (T - T')$, where N is the number of fixations actually recorded, and T and T′ are the total time spent reading and the time lost to the recording, respectively. Lost time was about 10% of total time on average.

2. Number of fixations per line (FIX/LIN). The larger the character size, the fewer words per line of text; hence, the more time lost to return sweeps of the eye and other aspects of overhead

unrelated to actual data sampling. Calculating the number of fixations per line gives a closer approximation to actual data acquisition within the framework of scrolling. Comparing number of fixations per line to total number of fixations can give some sense, albeit a weak one, of time and ocular work lost to overhead.

3. Number of words per fixation (WDS/FIX). Character size will influence the results of the preceding analysis inasmuch as there are twice as many words (approximately) in a line of 80 characters as in a line of 40 characters. Tallying fixations in terms of the number of words within the line gives the most analytical measure of the effectiveness of the visual data acquisition capability.

4. Rate of fixating (RATFIX). The rate at which readers move their eyes has long been a variable of particular interest (Kolers, 1976). The rate measure is composite, including both the duration of a fixation and the interfixation or travel time of the eye.

5. Fixation duration (DURATION). Presumably, the longer the time spent fixating a target, the more detail that is taken in, or is required to be taken in by the reader in order to process the information further. More difficult texts customarily take longer fixations.

6. Total time (TOTTIM). The standard or classical measure of performance is time on task.

Results

The main data have been summarized in Table 1 in terms of the six dependent measures described above. Note that for four of the measures the quantities indicated are number of fixations, but for the rightmost two the variable is time in seconds. The analyses of variance applied to the data yielded significant F-values only for main effects and for a few interactions of subjects with main effects; no interactions among the main effects themselves were statistically significant. The table will be described in the order of its rows.

(1) Spacing. Single spacing takes a few more fixations per line, slightly fewer words are read per fixation, and total reading time is slightly longer. Double spacing of course requires twice as much screen as single spacing does to display the same quantity of text. This doubling of space yields an improvement in performance of about 3% in number of fixations, and about 2% in total time to read a passage. The duration of individual fixations and the rate of fixating are unchanged by changes in spacing.

(2) Character size. Doubling the number of characters per line by halving their size increases the number of fixations per line from 4.82 to 8.00, but the total number of fixations per passage is fewer, the number of words acquired with each fixation is larger, the duration of each fixation is longer, but the overall reading time is shorter. To put it another way, the readers make fewer fixations but longer ones with the text made of smaller characters, apparently acquiring more information from the text

with each fixation. The analysis of spacing and character size clearly suggest that more densely packed text is read more efficiently in terms of ocular work and time than is more loosely packed text.

(3) Scrolling. Two sorts of scrolling were studied. In jump scrolling a line of text remains in place for some duration and then appears displaced upwards within a single raster scan, to be replaced by the next line. We studied this mode of scrolling with a small number of subjects with uniformly negative results: readers made many errors, often lost their place, and actively disliked this display mode. As described earlier under Displays, a smoother scrolling rate was substituted with the results shown in Table 1.

Two sorts of comparison may be made. One evaluates the data for positively scrolled texts (Slow, Optimum, Fast, and Double Fast); the other evaluates the difference between a Static page and a page scrolled at the reader's preferred or optimum rate. We consider these in turn.

The principal finding for positively scrolled texts is that performance improves throughout with an increase in scrolling rate. The number of fixations per line is fewer and the words acquired per fixation are more as rate increases from 10% slower than the optimum to 20% faster. Moreover, the average duration of fixations decreases. The paced nature of the task necessarily makes the total time shorter for the more rapidly scrolled text (99.92 sec compared to 76.71). The reduction of 27% in time for which the text is available is accompanied by a reduction in actual reading time of 23%, a reduction of 27% in total fixations and a reduction of 21% in fixations per line, but with an increase of 25% in the number of words acquired with each fixation. Moreover the duration of each fixation decreases by about 10 msec and the number of fixations increases, both quantities statistically significant by t-test.

Comparing the static page with the self-selected optimal scrolling rate indicates that the static page elicits fewer fixations both overall and per line, and that more words are acquired with each fixation directed at the static page than at the optimally scrolled page. In fact, with respect to these three quantities, the data obtained with the static page closely resemble the data obtained with the pages scrolled 10% faster than the subjects' optimum. The rate of fixating is slower with the static page but each fixation lasts for a longer time. Moreover, the total time required to read a passage is less for the static page than for the optimally scrolled page even when only those two times are compared in a separate analysis of variance [$F(1,20) = 10.24$, $p<.01$]. Thus, the data suggest that people read a static page more efficiently than a page scrolled at their self-selected optimal rate.

As remarked under Procedure, optimal scrolling rates were redetermined at the end of the third testing session. (The procedure was instituted only after the third subject was tested.) It will be recalled that the subjects read 16 scrolled pages during the testing, a quantity sufficient to reveal practice effects. The analysis of variance revealed a marked effect due to subjects--11 improved in speed but 6 set the rate slower on the second testing--and no main effect of practice ($F < 1$). The average scrolling rate was 1 line every 2.32 sec. at the beginning of testing and one line every 2.30 sec. at the end. Individual differences, it should be added, are marked throughout these analyses, yielding significant values of F in every test and often interacting with main effects. The magnitude of these differences can be appreciated from the ranges indicated in Table 1.

The method used to insure that subjects read the texts and did not just scan them was to test for comprehension after every passage. Analysis of variance of the scores yielded marginally significant differences among the subjects $F(19,76) = 1.96$, $p<.05$ but no interaction between subjects and any of the testing conditions, and no other significant main effects or interactions among them. The test was so arranged that 50% correct was the chance score. The scores obtained ranged from 79% to 96% with a grand mean of 88.77% The results suggest that the subjects read the passages with intent to comprehend and did comprehend their contents to a satisfactory degree. Hence the results reported above can be regarded as obtained from people engaged in motivated reading.

We may note, finally, that after the end of the third session the participants were asked whether they preferred the static or the scrolled pages. The results were that about 60% preferred the scrolled, the remainder the static pages. Presumably, some scrolling speeds were liked better than others, but our procedure did not allow us to make such inquiries.

Discussion

Books used to be made of small, densely packed pages. For unsure reasons, some having to do with notions of "mental hygiene", larger and more spaced texts became popular (Huey, 1908), the tradition prevailing still today. It is well known that character size and line length interact in their effects on readability; the size of the book page was determined in part by the size of the human hand holding the book, and the line lengths were determined accordingly. For the case of the CRT, page size is fixed by the point density of the screen; commercial television sets a standard of approximately 500 raster lines.

With such coarse grain, one might think that large, widely spaced characters would be read more easily. Our findings in this seem quite straightforward in suggesting the opposite, that smaller, more densely packed characters take less ocular (and presumably less cognitive) work to be read. People expend more fixations on large characters but they do not lead to any greater comprehension of the text. Rather, the large characters require more screen space and more time for their reading but with no gain that we have measured. We do not know whether the optimal character size lies between 40 and 80 or at some value still greater than 80. If the latter is true, there will surely be some point at which the dense characters make line-finding difficult. It is the latter difficulty that prompts many printed publications to keep lines short; presumably smaller print can be read without error if line finding on the return sweep is eliminated as a problem. Very narrow columns, as in newspapers, have been designed to allow the reader to scan vertically, without need of the return sweep. Columnar organization of text on a CRT could similarly be utilized, particularly if the textual material is designed for searching rather than detailed reading. These various considerations suggest a need for particular recommendations regarding organization of the electronic page. Uncritical extrapolation from printed page to electronic page may not be justified.

One way in which the electronic page differs wholly from print is in allowing for scrolling. Several advantages are available to this method. One, for example, would allow text to flow through a window, a few lines visible at a time. How many lines should be visible has not been studied yet. The results presented here cover the case of a window corresponding to 20 single space lines in height.

Our results suggest that scrolling has certain facilitative effects on reading, along with the pleasantness that Oleron & Tardien (1978) have ascribed to it. It can induce people to read more efficiently--that is, with fewer, shorter fixations, taking less time to accomplish the reading--at no apparent loss in comprehension. The rate at which the facilitation occurs is, however, something of a fly in the ointment. If the scrolling occurs at a rate less than the reader's optimum, the reader makes more fixations and longer fixations. As the rate is gradually increased, performance increases correspondingly, with best performance found at a rate 20% faster than the optimum scrolling rate.

To understand the significance of this finding, it is necessary to compare performance at the self-selected optimum scrolling rate with performance on a static page. In such a comparison, the advantage is with the static page: it is read with fewer fixations, in less overall time, and with more words acquired with each fixation. It seems clear to us, then, that subjects in selecting an optimal scrolling rate, actually set a rate which is somewhat below their true optimum. Performance on the static page, in fact, is at about the same level as performance on the page set 10% faster than their optimum; and performance on the page preprogrammed at 20% faster than optimum is better still (Table 1). Moreover, even the experience that came with reading 16 different pages of scrolled text did not induce the readers to increase their preferred scrolling rate to any reliable degree. For scrolling to be effective, therefore, the text would have to appear at least 20% faster than the reader requested; otherwise, the advantage rests with the static page. Certainly if self-selection of scrolling rate is permitted, then scrolling is likely to be less effective than a static page.

It will be realized that we have examined only ocular and cognitive efficiency in the control system acquiring the data from the page; we have not studied what the reader makes of the text, beyond being certain that the texts were understood. The recent report by Oleron and Tardieu (1978) mentioned above suggests that it is more difficult to reorganize or define for oneself a text that has been scrolled than a static text. Presumably the reader worries that the text will disappear, or the text does disappear, before reexamination occurs. Of course such considerations are unimportant for texts designed to be searched or matched rather than deeply understood. Speeded scrolling may be of serious advantage in such circumstances. This is but one of many questions that require study to ascertain the optimal methods for presenting information on electronic screens. It does seem clear that classical sources in respect to the printed page (Huey, 1908, Tinker, 1963) cannot be extrapolated wholesale to this newer medium. It should be realized also that the analysis of eye movements in respect to performance provides a texture of explanation that cannot even be inferred from a study of only time on task.

Acknowledgment

The eye tracker and its software support together constitute a highly sophisticated laboratory system. I acknowledge with gratitude the contributions of several coworkers and associates to developing the system and collecting and analyzing the data. Chief among them are Dennis Ferguson and Robert Duchnicky, working immediately in my laboratory. Daniel Guerin and Mario Ruggiero of the small systems research support facility of the University of Toronto Computer Centre, and Eugene Siciunas, Manager of that facility, organized and developed the basic system software and supportive hardware.

Appendix 1: System Description

This appendix provides a brief description of the instrumentation, display and data collection apparatus utilized in the collection and analysis of the data presented in this report.

In short, the experiment consisted of having subjects read passages of text from a a CRT display which was highly similar in appearance to a a home television set, while their eye movements were simultaneously recorded. A Digital Equipment Corporation PDP-11/03 minicomputer with dual 8" floppy disk drives was used both to produce the displays and record eye movements, as well as for much of the subsequent data analysis. A 23" Electrohome TV monitor was used for display, slaved to the video output of a DEC VT100 ASCII CRT terminal.

The eye position information was aquired using a commercially available Whittaker Corporation (now Gulf + Western Applied Science Laboratories) Series 1900 Eye View Monitor. With this instrument, the eye is illuminated with low level, near infrared light and a TV image of the pupil obtained with a sensitive Silicon Matrix Tube television camera. The subject's eye rotation and consequently his point of fixation is determined by the measurement of the position of the center of the pupil with respect to the corneal reflection of the light source. These two features of the eye move differentially with eye rotation, hence the difference is indicative of the eye's point of fixation independent of moderate head movements. The two eye position coordinates (x,y) and the pupil diameter (p) are output in digital form at a rate of 60 samples per second.

Appendix 2: Fixation Analysis Algorithm

The raw data consists of three values; two eye position coordinates (x and y) and a measure of pupil diameter (p). The fixation analysis algorithm acts upon the raw data to segment it into fixations and movements.

The algorithm is based upon two key features. First, the eye is "fixating" as long as the data points remain within a selected radius; on the basis of preliminary analyses, that value was set at 12 raster lines, which is approximately 1.5 degrees of visual angle. This value sets the resolving power of the system. Second, the eye is "in movement" as long as the distance between two consecutive points is greater than a specified parameter and the second of the two points falls outside the circle.

Before being classified as belonging to either a fixation or a movement, each data point is checked to see whether the x, y, and p values lie outside a previously specified range, which would have carried it off the screen (x and y), or which signaled exceptional changes in pupil size, including blinks. If a point does exceed the range it is flagged and given a special status (Reject), otherwise it is considered "good". Data values exceeding the Reject levels may arise for a number of reasons, including blinks of the eye, very large pupils, and transients.

The algorithm begins by searching for two consecutive "good" points; their geometric centre defines the centre of the above-mentioned circle. The rest of the data are then processed one point at a time.

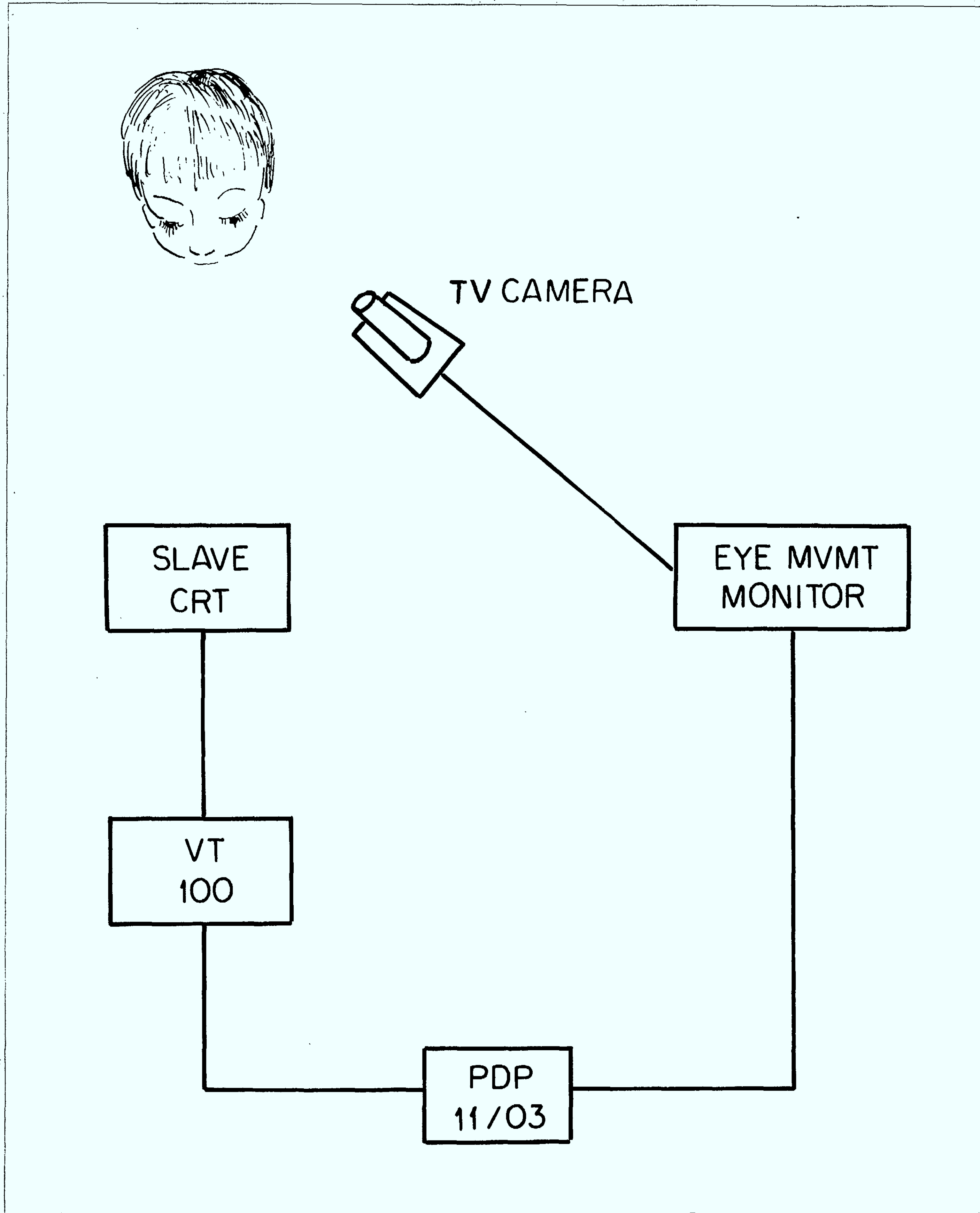
Fixations are terminated in three ways; either the data points begin to fall outside the circle, or a movement begins, or the fixation is truncated by a Reject. "Fixations" whose durations were less then 100 msec were excluded from further analysis, on the assumption that they were falsely classified (Levy-Schoen & O'Regan, 1979).

TABLE 1: SUMMARY OF MAIN RESULTS

Independent Variables	Dependent Variables					
	NUMFIX	FIX/LIN	WDS/FIX	RATFIX	DURATION (sec)	TOTTIM (sec)
SPACING:						
Single	241.Ø	6.52	1.31	2.69	.263	89.21
Double	233.5	6.3Ø	1.36	2.67	.264	87.29
F(1,76)	9.12**	11.Ø4**	1Ø.87**	1.36	Ø.Ø1	7.41**
% Difference	3%	3%	4%			2%
CHARACTER SIZE:						
Small(8Ø)	212.7	8.ØØ	1.46	2.62	.282	81.32
Large(4Ø)	261.8	4.82	1.2Ø	2.74	.245	95.19
F(1,76)	381.62**	2472.7**	285.8**	33.97**	148.5**	387.71**
% Difference	23%	66%	22%	4%	15%	17%
SCROLLING RATE:						
Ø Static	227.7	6.19	1.38	2.56	.275	88.18
-1Ø% Slow	267.8	7.22	1.18	2.68	.266	99.92
1 Optimum	25Ø.4	6.74	1.26	2.7Ø	.261	91.94
+1Ø% Fast	229.5	6.19	1.36	2.7Ø	.258	84.53
+2Ø% Double Fast	21Ø.8	5.7Ø	1.48	2.75	.256	76.71
% Difference: Scrolling	27%	21%	25%	3%	4%	23%
% Difference: Optimum-Static	1Ø%	9%	1Ø%	5%	5%	4%
Range	167-3Ø4	4.58-8.25	1.Ø2-1.82	2.37-2.95	.22Ø-.311	65-127
Grand Mean	237.Ø	6.41	1.33	2.68	.263	88.25

** p<.Ø1

Figure 1.



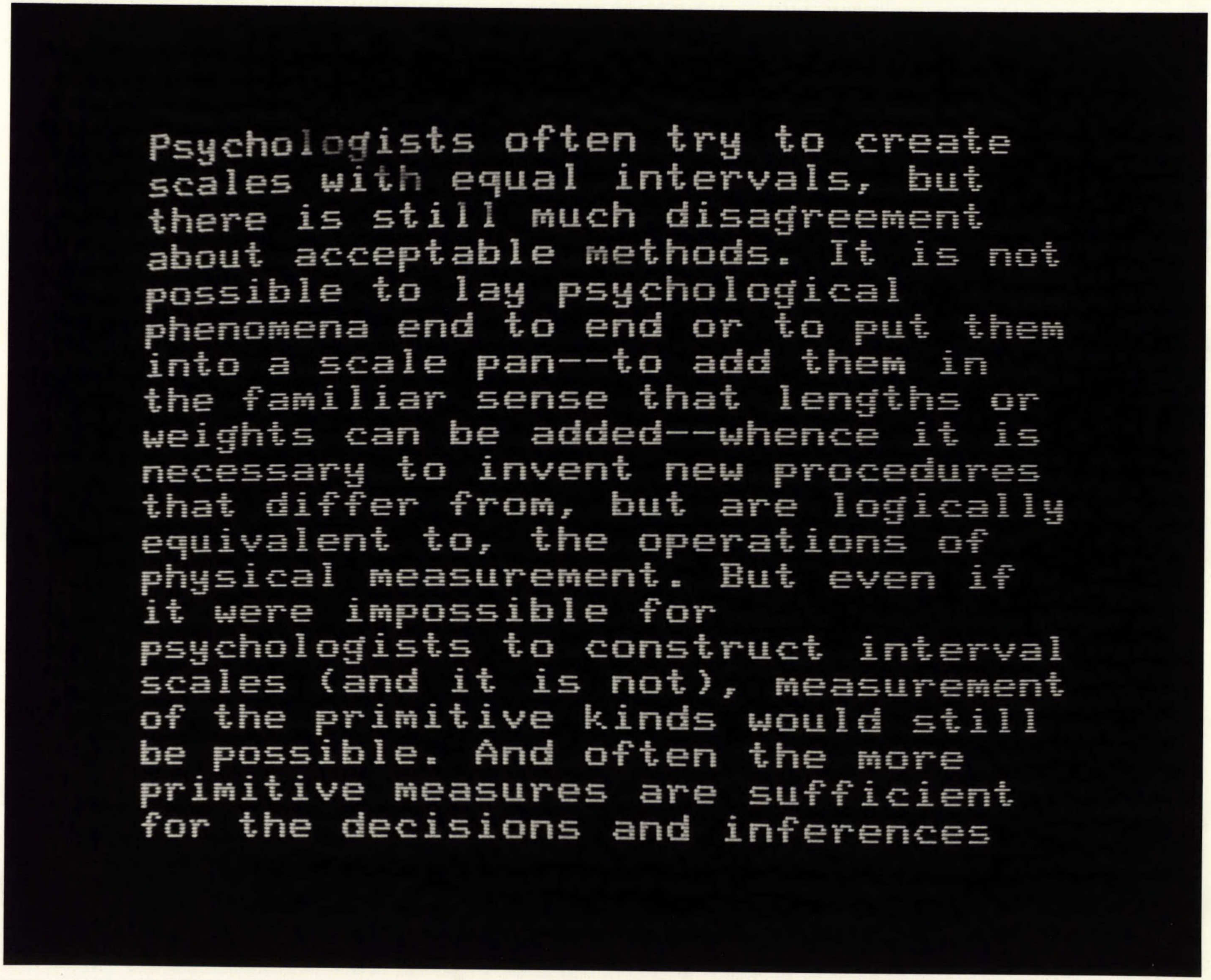

Psychologists often try to create
scales with equal intervals, but
there is still much disagreement
about acceptable methods. It is not
possible to lay psychological
phenomena end to end or to put them
into a scale pan--to add them in
the familiar sense that lengths or
weights can be added--whence it is
necessary to invent new procedures
that differ from, but are logically
equivalent to, the operations of
physical measurement. But even if
it were impossible for
psychologists to construct interval
scales (and it is not), measurement
of the primitive kinds would still
be possible. And often the more
primitive measures are sufficient
for the decisions and inferences

Figure 2(a).

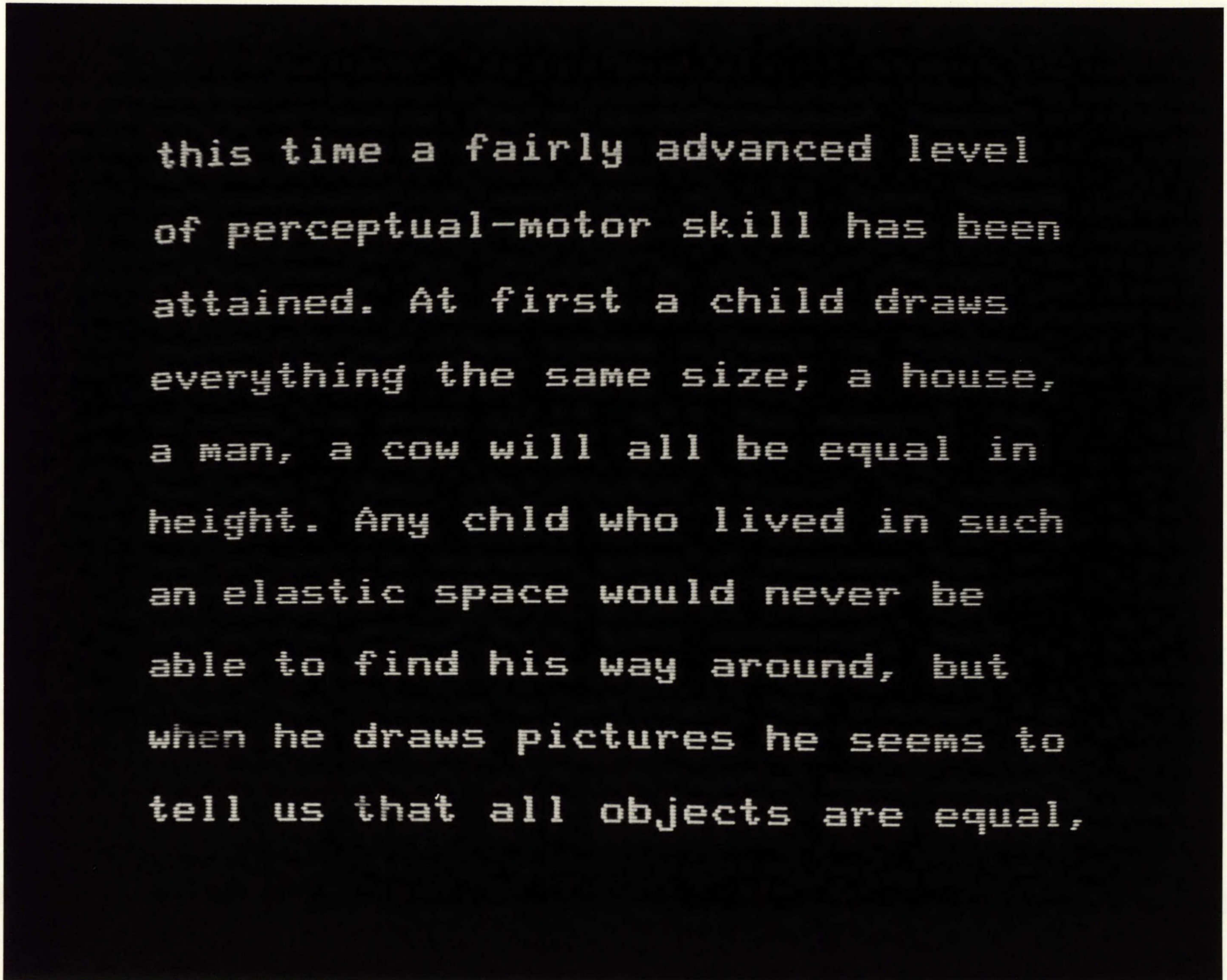

this time a fairly advanced level
of perceptual-motor skill has been
attained. At first a child draws
everything the same size; a house,
a man, a cow will all be equal in
height. Any chld who lived in such
an elastic space would never be
able to find his way around, but
when he draws pictures he seems to
tell us that all objects are equal,

Figure 2(b).

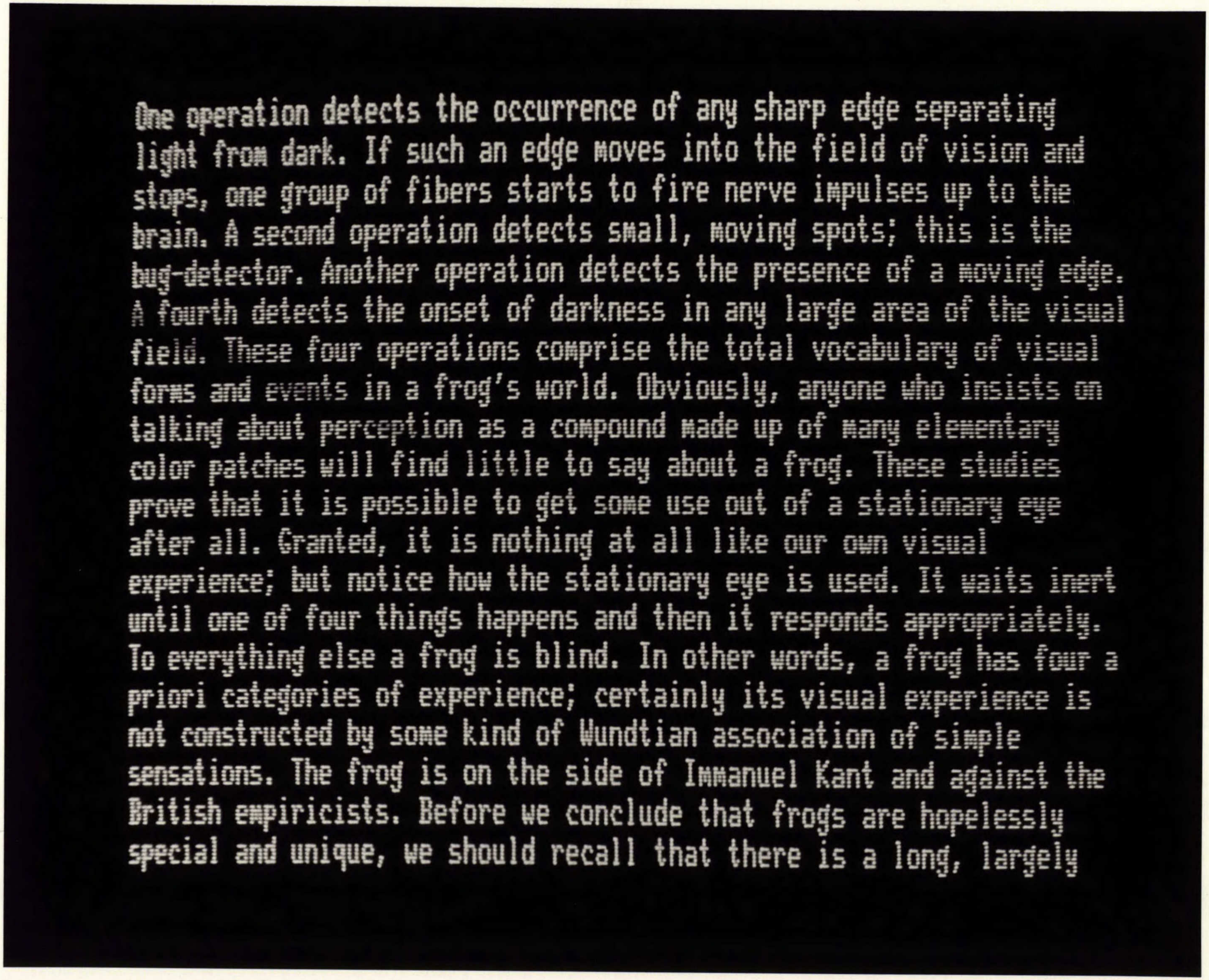
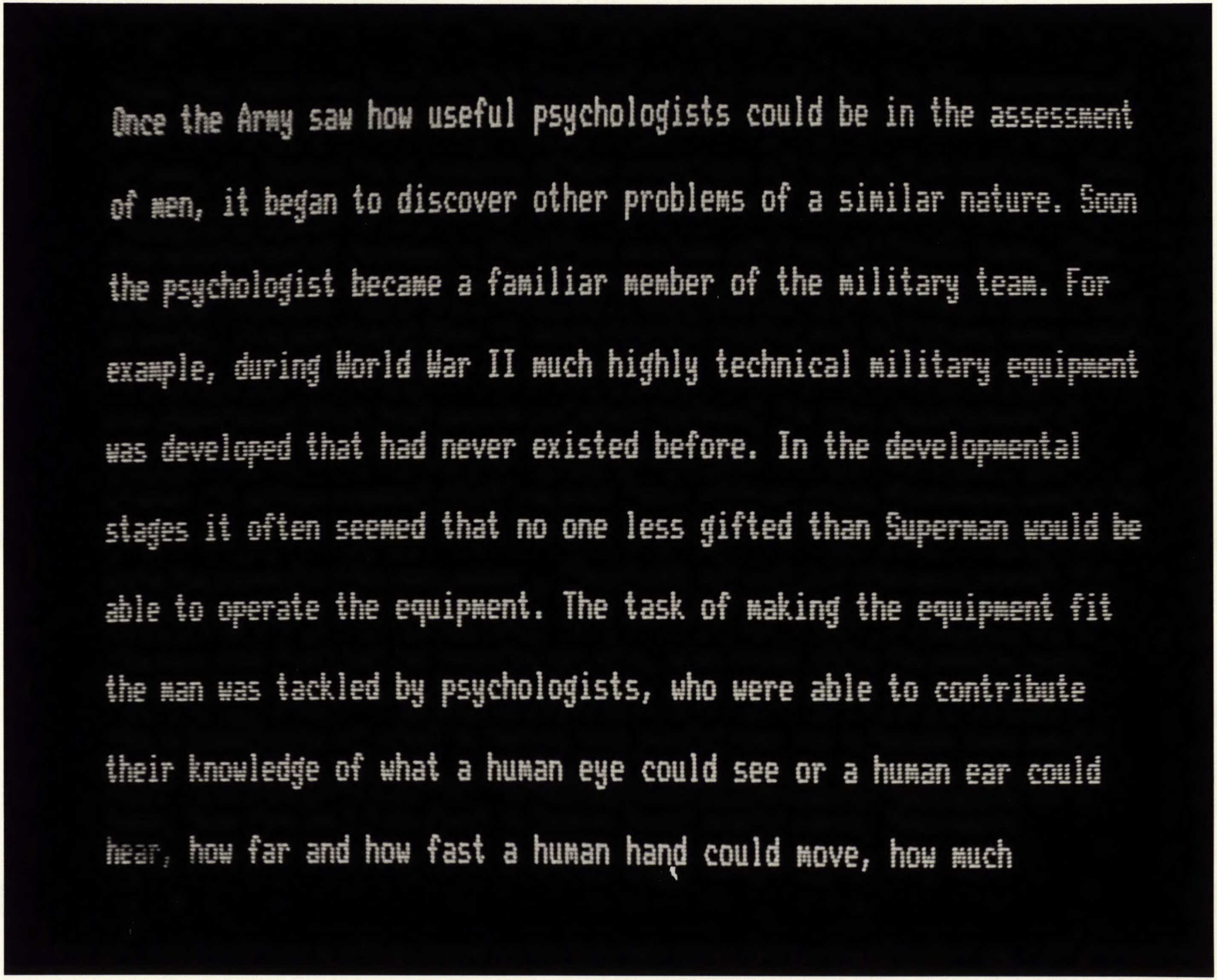

One operation detects the occurrence of any sharp edge separating
light from dark. If such an edge moves into the field of vision and
stops, one group of fibers starts to fire nerve impulses up to the
brain. A second operation detects small, moving spots; this is the
bug-detector. Another operation detects the presence of a moving edge.
A fourth detects the onset of darkness in any large area of the visual
field. These four operations comprise the total vocabulary of visual
forms and events in a frog's world. Obviously, anyone who insists on
talking about perception as a compound made up of many elementary
color patches will find little to say about a frog. These studies
prove that it is possible to get some use out of a stationary eye
after all. Granted, it is nothing at all like our own visual
experience; but notice how the stationary eye is used. It waits inert
until one of four things happens and then it responds appropriately.
To everything else a frog is blind. In other words, a frog has four a
priori categories of experience; certainly its visual experience is
not constructed by some kind of Wundtian association of simple
sensations. The frog is on the side of Immanuel Kant and against the
British empiricists. Before we conclude that frogs are hopelessly
special and unique, we should recall that there is a long, largely

Figure 2(c).



Once the Army saw how useful psychologists could be in the assessment of men, it began to discover other problems of a similar nature. Soon the psychologist became a familiar member of the military team. For example, during World War II much highly technical military equipment was developed that had never existed before. In the developmental stages it often seemed that no one less gifted than Superman would be able to operate the equipment. The task of making the equipment fit the man was tackled by psychologists, who were able to contribute their knowledge of what a human eye could see or a human ear could hear, how far and how fast a human hand could move, how much

Figure 2(d).

Figure 3(a).

What are some operations of measurement?

What sorts of scales have natural zero points?

Do biologists agree about which things are alive and which are not?

Who will be the last to discover water?

Which word should be banned for a decade or two?

Is it impossible for psychologists to construct interval scales?

What is similar to tugging at one's own bootstraps?

Why are the social and behavioural sciences sometimes criticized?

What word has been worn smooth by a million tongues?

What is a ratio scale?

Figure 3(b)

What was the experiment in role playing?

What is a result of an advanced perceptual-motor skill?

When do the children express dismay?

Who showed the greater change in opinion?

What are the children loaded with?

What is produced by active participation?

What do the pictures seem to say?

Must one believe an argument to remember it?

Does a person come to believe what he or she is saying?

What are the outcomes of early experiments on linearity?

Figure 3(c)

How is the stationary eye used?

In what atmosphere are the questions asked?

What kind of illness does the patient have?

On whose side philosophically is the frog?

Which tradition prefers sorting to associating?

What kinds of data should he collect?

What is the vocabulary of events in the frog's world?

Will he cooperate with the therapist?

Where does the clinical-statistical argument arise?

What happens when an edge moves into the field of vision?

Figure 3(d).

How did the psychologists help?

Did children have better imagery?

What was the experimenter's motto?

Who is concerned with the alternation of intervals of rest and work?

Were his first subjects scientific acquaintances?

What task did the psychologists tackle?

Who helped to heal the mentally wounded?

Which image was the clearest?

What is the trade name of a large and active sector?

What might be antagonistic to abstract thought?

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