COMPARISON OF MEANS AND MEDIANS IN THE REDUCTION OF VISUAL EVOKED POTENTIAL DATA

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ABSTRACT

Means and medians of visual evoked potentials were compared to determine if the medians would provide less noisy results than the means or require fewer samples for the same noise. The means and medians of a 100 onset-offset checkerboard VEPs were computed and plotted for (1) the full sample, (2) the first and second 50; (3) the first 25. In addition, running means were examined. Comparable means showed less scatter than the medians. A N_{340} wave was seen in the mean of the second 50 VEPs not observable in the first 50. A running mean of 3 gives a curve as useful as the mean of 100 with only 50 VEPs within the first 250 msec. Samples of 25 VEPs are not adequate to provide a useful waveform but may be used to determine economically the peak amplitude with a potential error of less than 4%. This can be useful in the objective measurement of visual actuity.

I. Introduction

The processing of evoked potential data is primarily a signal-to-noise ratio problem. The nonstationary or transient signal is of the order of 1/10 or less the amplitude of the noise. The principles of neurobiological signal analysis have been treated generally and extensively by Glaser and Ruchkin.[5]

In visual evoked potentials the primary noise is the electroencephalographic potentials with a peak-to-peak amplitude of the order of 50μv. Generally the signal is extracted from the noise by averaging, finding the mean of 50 or 100 samples of visual evoked potentials or blocks. As is well known, the signal, being time-locked to the stimulus, increases directly with the number of samples; the noise being random relative to the stimulus increases with the square root of the number of samples.

II. Background

The noise may not be entirely random in the sense that movement artifacts can cause large relatively infrequent departures, and results that lie well outside the usual distribution of noise. There are techniques to eliminate these outliers. It can be done manually by recording each sample trace on magnetic tape and rejecting any trace on subsequent inspection that shows an amplitude which extended beyond an arbitrary criterion. This procedure can also be done automatically with an electronic amplitude window.

In considering the design of a microprocessor-based VEP machine[7] it occurred to us that if such outliers did distort the averaged evoked potential it might be better to use the median rather than the mean. The primary advantage over an electronic amplitude window would be that no arbitrary amplitude would have to be chosen. If the window is too large it is useless and if too small the VEP wave form is clipped and distorted. A median would automatically eliminate large, infrequent outliers. An early consideration of the median was made by Rosenblith in 1962.[9] Employment of the median was suggested by Borda and Frost in 1968.[3] As discussed in Glasner and Ruchkin (p. 196)[5], median evoked responses have been shown to provide greater insensitivity to larger artifactual noice. It also yields a substantially poorer (higher standard deviation) estimate of the signal compared to the average in those cases when the noise is artifact free. Since the result depends on the kind of signal being processed, we decided to record onset-offset VEPs to compare the means and medians of the samples in whole and in part. We also examined running averages which are in effect low-pass digital filters. The results have provided us with some guidance on the processing of VEPs and the required number of samples.

III. Method

A. Stimulus

A square checkerboard 10^{0} on a side with detail of 12.5 minarc, or Snellen 20/250, was presented. Onset-offset time was 60 msec after which the same average illumination was seen in the uniform field. The total period lasted 750 msec. Contrast was 70% and the maximum luminance was 50 c/m^{7}. The stimulus was presented with slide projectors and electromagnetically controlled shutters in another room and retroprojected on a translucent screen at 2 meters from the eyes.

B. Recording

Grass EEG electrodes were placed 2 cm above the inion on the midline (active), on one ear lobe (remote) and on the other lobe (ground). Impedance between any two was less than 3kΩ. Two Grass p-15 AC preamplifiers in cascade gave a gain of 10^5 with a half-amplitude band width set at 1 and 100 Hz. The output at ±0.5 volts maximum was fed into an FM instrumentation recorder on 1" tape at 7½ inches per sec. One channel carried the data and there was an extra stimulus synchronization signal on another in the form of 2V, 10 msec square wave. The tape was transformed from analog to digital with 11 bit accuracy by a Modcomp II computer with appropriate programming. Analysis of the digital tape was done on a Control Data Corporation 6400 computer with appropriate Fortran programs and graphics. The data in the memory bank were fitted into 700 one msec bins. In plotting, each horizontal (or X axis) dot represents 5.56 msec, there being 9 dots for 50 msec. Thus, the 5 or 6, 1 msec bins are combined if the amplitude (or Y axis) values are similar but are separate if not. On the vertical Y axis each dot represents 8.33 units of amplitude when there are 6 dots for 50 divisions and 10.00 units when there are 5 dots for 50 divisions. The total positive range is 300 divisions which is equal to 3 μv making each vertical scale dot 0.083 μv or 0.100 μv depending on whether the 6 or 5 dot separation is used. If the amplitude of the 5 or 6 bins between dots on the horizontal or X axis lies within one vertical pair of dots (±0.042 μv for 6 dot separation or ±0.0500 μv for 5 dot separations), a single point is printed for these bins (low frequency or steady response). If the values are spread out (high frequency or noisy response) then multiple points are printed in the same vertical column. It can be seen at a glance how much high frequency residual noise the data exhibit.

IV. Results

A. Comparison of Mean and Median for the Same 100 Blocks of Data

Figure 1 shows the mean of 100 blocks of data, that is a 100 VEP s. Figure 2 shows the median curve of the same data. It is evident that the median is noisier than the mean. This result is to be expected if the noise in the raw data has a distribution approximately Gaussian. If, on the other hand, there were extreme values, irregular outliers, one might expect the median to be less noisy than the mean. It can be inferred, therefore that raw data here are without significant extreme outliers.

B. Comparison of Mean and Median for 50 and 25 Blocks

When the mean and median curves are compared for blocks of 50, the mean is still better. Blocks of 25 give noisier curves, but the mean remains superior to the median. The median curves are not presented here.

C. Comparison of the Means of the First Block of 50 with the Second Block of 50

Figures 3 and 4 show the first and second blocks of 50 respectively, each separated from the original 100 blocks. They seem very similar except for a negative (downward) wave at a latency of about 340 msec (N_{340}) in Fig. 4 but not in Fig. 3. This wave is also visible in Figs. 1 and 2. These longer latency waves are generally considered to be associated more with cognitive rather than with sensory or perceptual processes, and there is a large literature in this field (for example - see Barber[1] and Begleiter[2]). It is possible that the subject became bored or daydreamed more in one half of the run than the other. It indicates the desirability of extending the experiment for the examination of longer latency phenomena than for short.

D. Running Means and Medians

In a series of experiments, blocks of data, 100 50, and 25 were processed to give running averages (effectively low pass digital filtering) both mean and median, in groups of 3, 10, 25 samples. If the underlying signal does not vary rapidly in time, these smoothings may be expected to reduce the noise and not affect the signal substantially. They are useful for variable latencies as well.

Running means of 3 with a block of 100 gave virtually the same results as the straight mean, Fig. 1. The running mean of 3 for 50 blocks, Fig. 5, appears the same in form but smoother and therefore, better than the mean of 50 blocks, Fig. 3. In fact, the running mean of 3 for 50 blocks, Fig. 5, appears as good as the mean of 100 blocks, Fig. 1, using half the blocks and recording time, as long as the interest is in relatively short latencies, within 250 msec. The running median of three for 100 blocks exhibits much smoothing, although much of the detail is retained, Fig. 6. However, a similar result is obtained with fewer samples by the running mean of 3 with 50 blocks. The same can be said for the similar running medians.

A running mean of 25 shows too much distortion to be useful in recording the waveform, whether they be means or medians, straight or running. Also running means and medians of 25 smooth the data to a loss of detail and are not at all useful for waveform analysis.

E. Peak Amplitude

There are programs where the VEP waveform information may be sacrificed because a peak amplitude is adequate, for example, in an objective visual acuity program[8]. An analysis was made of the peak amplitudes of the mean for 100 blocks, the mean for each of the two blocks of 50 and the mean for a block of 25. The latter is seen in Fig. 7. These values were 2.42, 2.37, 2.48, and 2.33 μV respectively. The difference and presumed error was not greater than 3.72% in using the blocks of 25 but the saving in blocks and time of recording was up to three-fourths. This error is trivial, compared to the great time saving when only amplitudes are required.

V. Discussion

Our subject was a young male adult who was an experienced VEP subject. The conclusions we have drawn are for his data. It is possible that the median could be superior to the mean for a restless child who generates more movement artifacts. However, we think our results are applicable for most subjects.

Figure 1 showing the means of 100 VEPs compared well with the mean curve derived through our regular clinical mean averaging system, based on an Intellec computer (microprocessor, Intel 8008). The curve was drawn with an X-Y plotter which attenuated the higher frequencies (Fig. 8). This smoothing action was introduced into our computer print-out curves by employing the running mean. The comparison also shows that despite all the processing, FM tape, analog to digital conversion and computer averaging programs, the curve maintained its basic characteristics.

Our interest in the treatment of VEP data was stimulated in designing a microprocessor-based instrument to extract as economically as possible, relative to doctor-patient time, objective acuity measurements. Calculation of a median requires retention of all the values or acceptance of an approximation[5]. Calculation of the mean requires retention of the running sum and the number of samples to date. Thus there is an advantage of the mean over the median as far as computation is concerned. This, in addition to our graphic results, leads us to drop consideration of a median program for the present.

Our conclusions are in agreement with the experiences of other investigators in related situations. The mean has substantial analytic and statistical advantages over the median so the results obtained are gratifying. The median is known to distort certain signals substantially[10].

In future studies it would be worth considering the use of trimmed means where both ends of the sample distribution are truncated. A trimmed mean has the advantage of being virtually the same as the mean itself when no outliers are present. Analytic properties of such estimates are explored in Brillinger, 1980[4].

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LEGENDS

Figure 1. Mean of 100 VEPs or blocks. For explanation, see text.

Figure 2. Median of 100 VEPs or blocks. For explanation, see text.

Figure 3. Mean of the first 50 VEPs or blocks. For explanation, see text.

Figure 4. Mean of the second 50 VEPs or blocks. For explanation, see text.

Figure 5. Running mean of 3 for the first 50 blocks. For explanation, see text.

Figure 6. Running median of 3 for 100 VEPs or blocks. For explanation, see text.

Figure 7. Mean of the first 25 VEPs or blocks. For explanation, see text.

Figure 8. Mean of 100 VEPs plotted with an X-Y recorder. .

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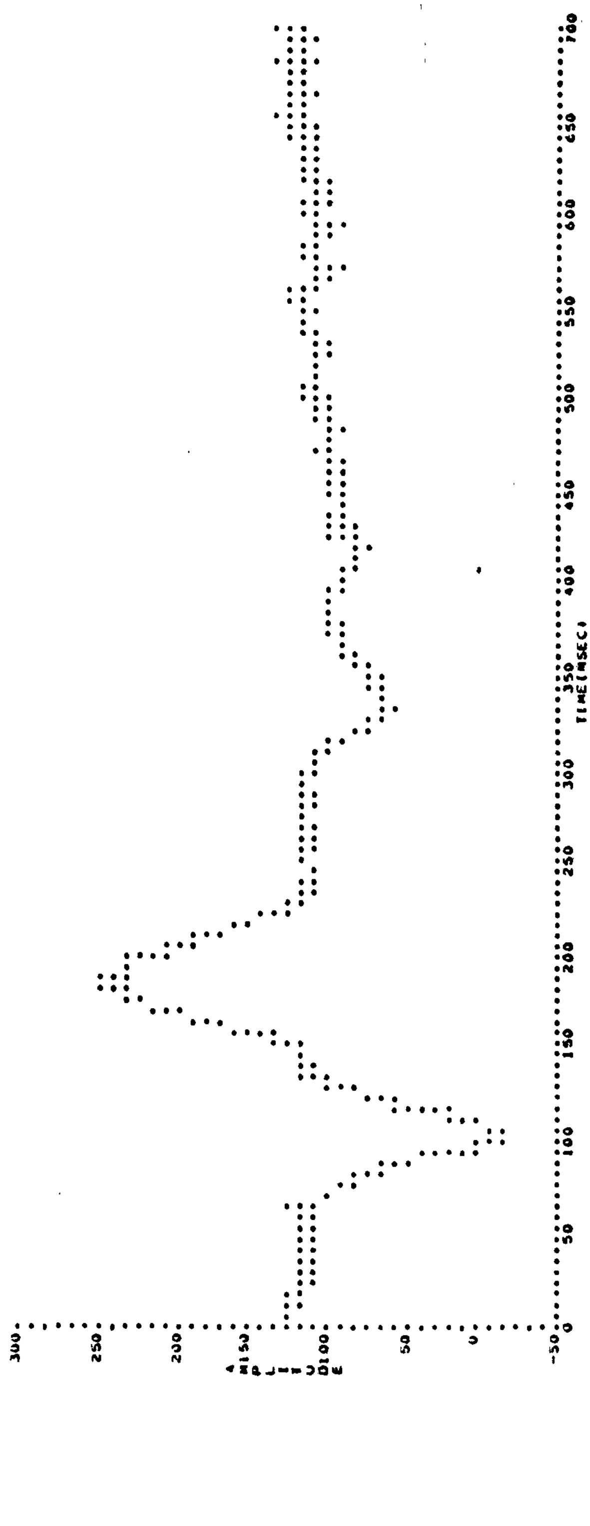
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Fig. 1

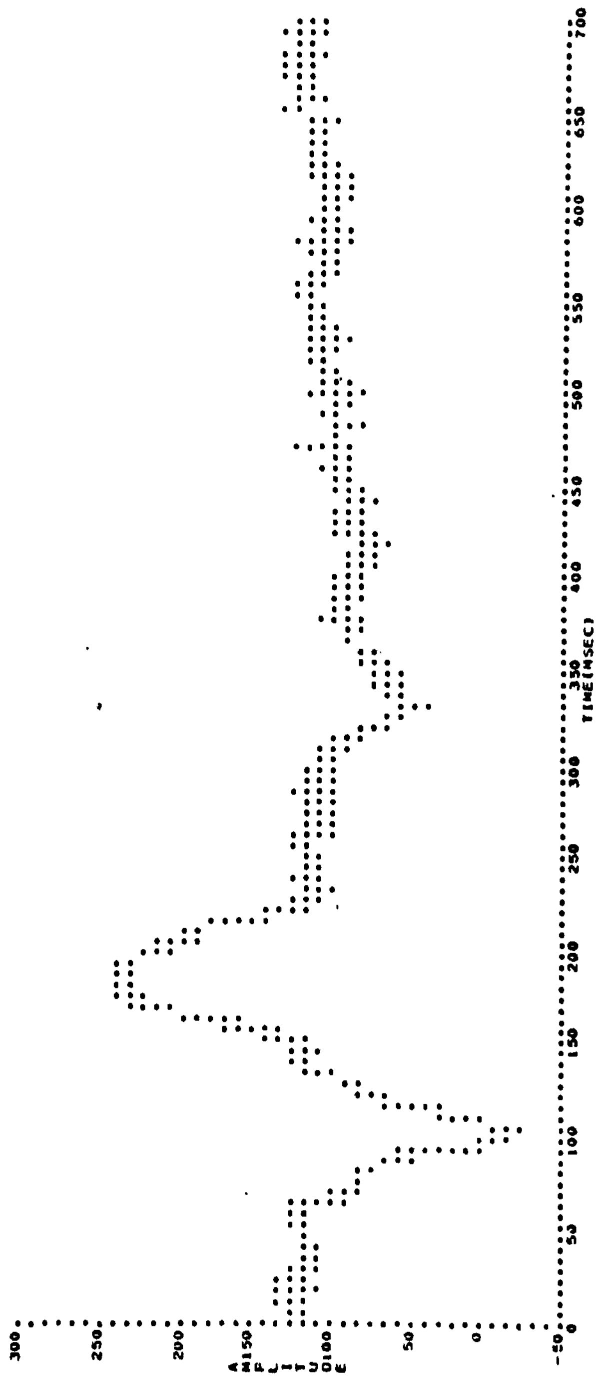

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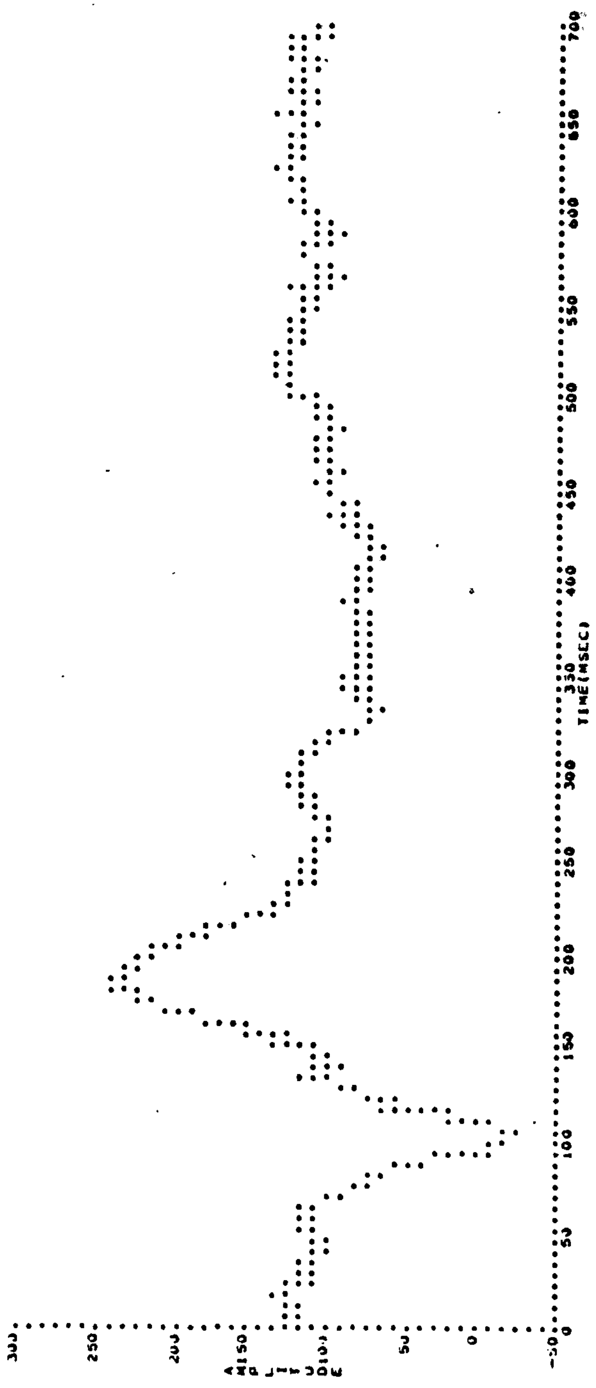
Fig 2



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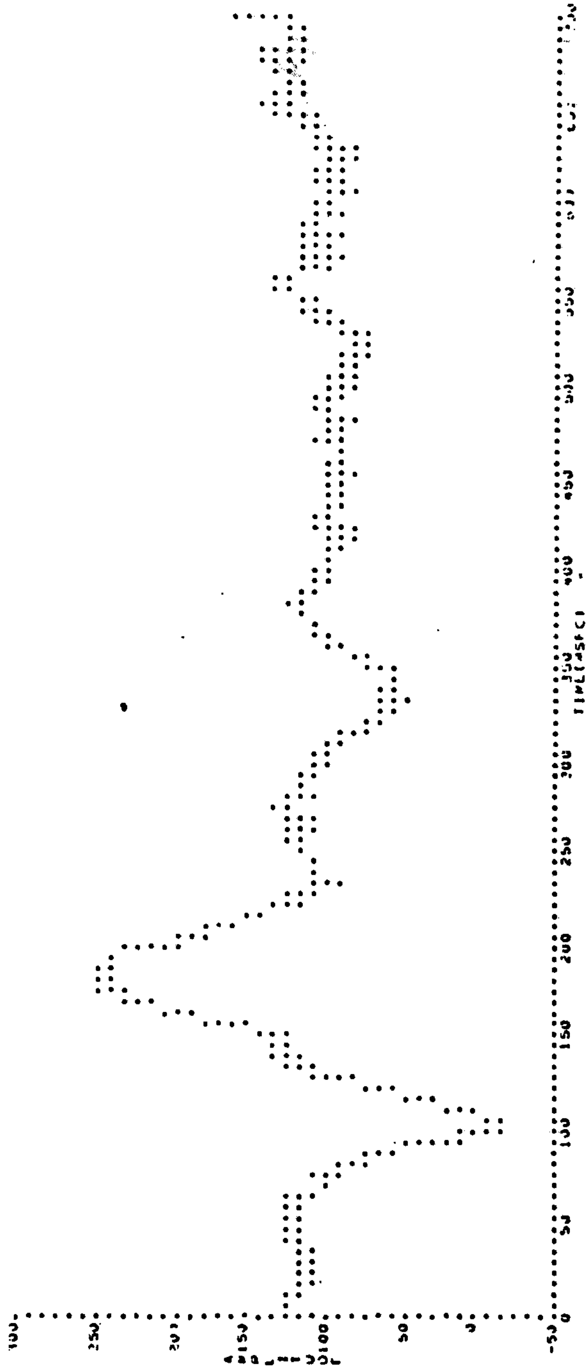

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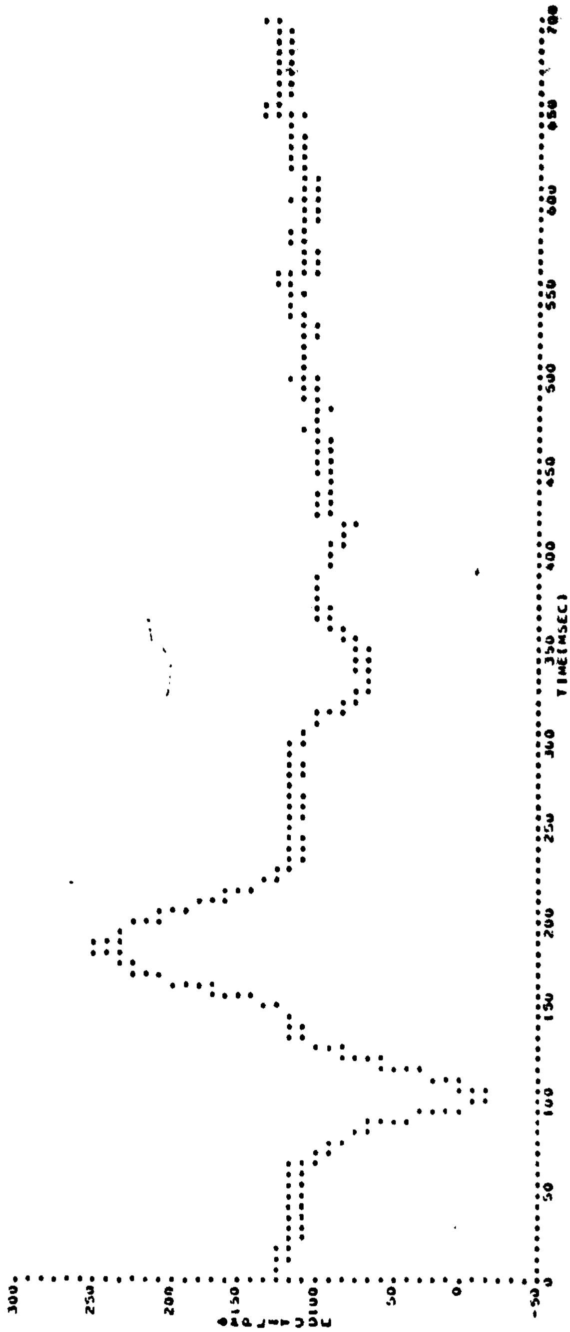

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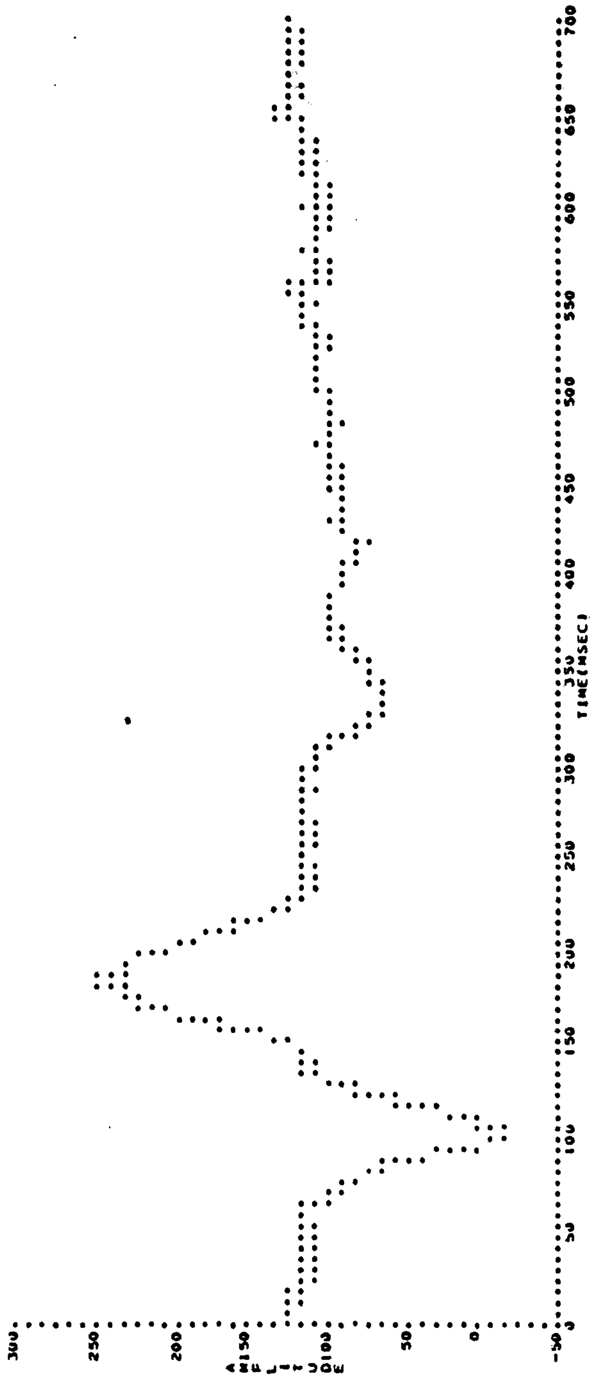
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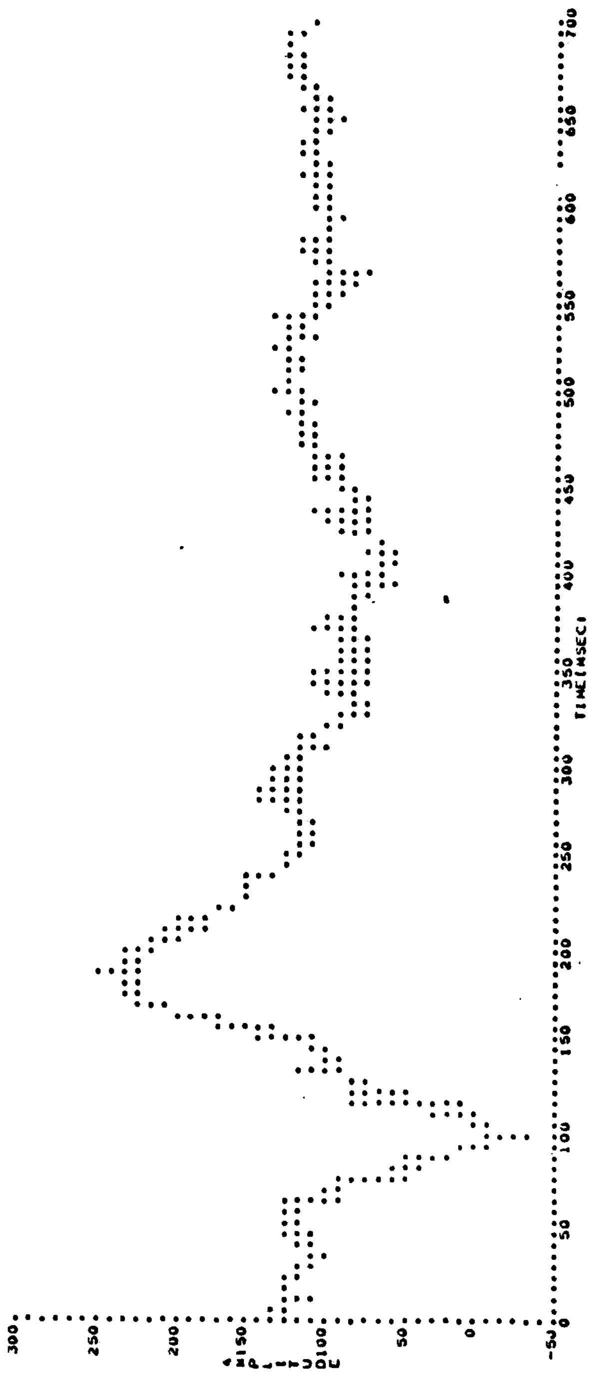

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Fig. 7

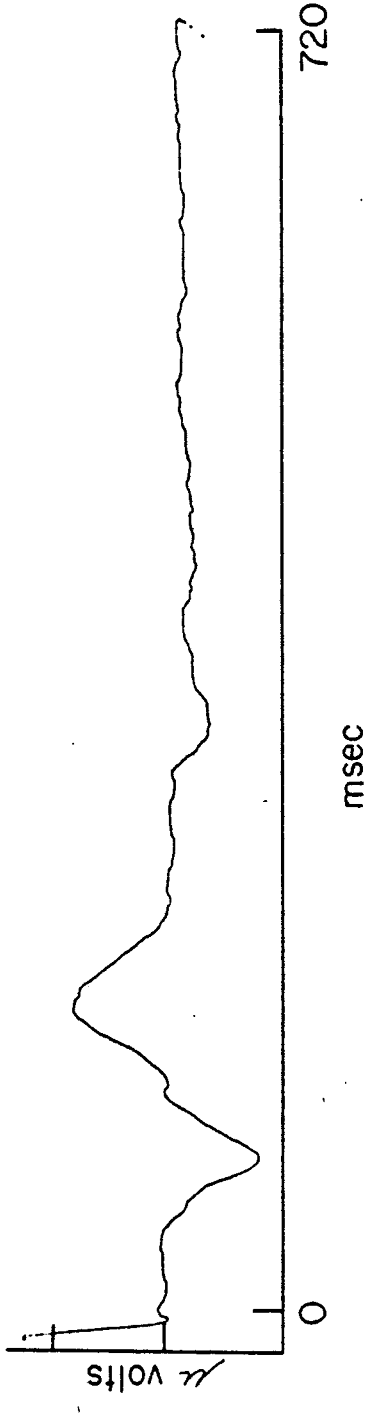

Fig. 8

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