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In 1969 a long series of studies were initiated aimed at exploring the possible effects of weak ELF fields on behavior of monkeys in the laboratory. It seemed obvious, at the outset, that low frequency fields at levels of 1-100 V/m p-p were not likely to produce dramatic, sudden onset, behavioral changes. Fields at those levels are routinely encountered in the home around 60 Hz devices. It was taken as a challenge to find a (1) highly sensitive but reliable behavioral assay that could, in principle, (2) detect thresholds and

would allow (3) long exposure durations. For example, it seemed vain to think that five minutes of exposure to a 45 Hz field at 10 V/m would affect any behavior at all. A final requirement, based on repeated references in the literature to reaction time, circadian rhythums, etc., was that the task involve some kind of (4) "timing" behavior. These four requirements all seemed to be met by employing an interresponse time schedule of reinforcement (IRT task) in which an animal is reinforced for pressing a lever once every N sec within a specified period ("limited hold"). If the animal presses too early or too late, the timer recycles. In these studies, the animal was reinforced with a tiny squirt of apple juice for pressing the lever every 5 sec within a 2.5 sec limited hold. Exposures were four hours long anf test periods were three hours long. In approximately 300 experiments, four 4-hour replications of each field exposure plus an intermingled no-field tests were done for each of five monkeys. Evidence was discovered for a shift in the direction of shorted inter-response times in the presence of fields of a given frequency and voltage within a range from 1-100 V/m and 7 to 75 Hz.

Four major conclusions were drawn from this study:

(1) Frequency-specificity. The evidence for a low threshold for 7 Hz is most interesting. Analagous frequency-specificity changes in calcium efflux (6) in in vitro neonatal chick brains have been observed in our laboratory.

(2) Voltage. The data suggest some degree of dose-dependency. Results at 100 V/m p-p were inconclusive and suggest either a voltage-window of the kind observed by Kalmijn (and in the calcium efflux studies) or a 24-hour carryover effect.

(3) Duration of exposure. Relatively long exposure durations appear to have contributed to the systematic array of results.

(4) Behavioral assay. The question of external stimulus control. The IRT task apparently was adequately sensitive and reliable. A comparison of our results with those of other negative primate studies revealed that in the negative studies, behavioral assays included more traditional tasks, including reaction time tests, fixed interval tests, match-to-sample tests, etc., typically administered in 15-minute intervals. Animals were deprived of food and water and exposed to a variety of light and sound cues regulating the various tasks. In the IRT task, the monkeys were isolated; they were not deprived during testing; there were no sound or light cues regulating their behavior. It might be said that the animals were forced, by the nature of the timing task, to pay attention to their own internal milieu.

"AN EVALUATION OF POSSIBLE EFFECTS OF MODULATED
76 Hz ELECTRIC FIELDS ON BEHAVIOR AND EEG OF MONKEYS.
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ONR FINAL REPORT
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June 1980

I. INTRODUCTION

Over the past several years, there have been some dramatic results reported in observational studies (as contrasted with laboratory studies) of the role of weak ELF fields in affecting the survival behavior of certain species. One example of such a study is that of Kalmijn (1) in which he demonstrated that sharks use weak, ELF fields to detect their prey. In an ingenious series of experiments, Kalmijn demonstrated that sharks detected a flat fish buried in sand at the bottom of a large hold tank on the basis of the weak ELF field emitted by the flat fish. Kalmijn estimated this field to be on the order of .2μV/cm and to cause slowing of respiratory rhythms. When non-electric cues were systematically eliminated by the use of an agar chamber, the shark continued to dive immediately to the buried flat fish. However, the introduction of a thick polyethelene film placed around the prey attenuated the electric field and succeeded in confusing the shark. When the natural field of the flat fish was simulated with a .4μV/cm field at 5 Hz produced by two electrodes buried in sand at the bottom of the tank, the shark dove immediately to the location of the electrodes. In later experiments, Kalmijn observed a voltage window; i.e., the effect was not observed if a substantially higher voltage simulation was used. Special receptors, the ampullae of Lorenzini, were discovered to account for the shark's perception of the weak fields.

Other observational studies have been done on the homing and migration of birds. The study of Keeton (2) is especially interesting. Although this study employed weak magnetic fields rather than electric fields, it is described briefly here because of an important methodological point. Keeton strapped tiny magnets on the backs of homing pigeons and observed that their flight was, consequently, disoriented but only on cloudy days. He concluded that if the sun were present as a salient cue, the pigeons could only be observed when strong external cues guiding their behavior were absent.

New evidence for disruption of migration by weak ELF fields has recently been offered by Williams, Williams, Larkin and Sutherland (3). They have observed that migratory birds showed a deviation in flight direction of 5° to 25° around the Seafarer antenna, when the N-S axis was energized. Indications were that flight direction was rapidly corrected. This field was estimated to be .17 V/m rms at 10 meters, perpendicular to the antenna.

These observational studies raise the question of whether they represent merely isolated peculiarities of nature or whether they point towards some fundamental property of nervous systems that extends throughout the animal kingdom, including man.

In 1969, we began a long series of studies (Gavalas, Walter, Hamer and Adey (4), Gavalas-Medici and Day-Magdaleno (5)) aimed at exploring the possible effects of weak ELF fields on behavior of monkeys in the laboratory. It seemed obvious, at the outset, that low frequency fields at levels of 1-100 V/m p-p were not likely to produce dramatic, sudden onset, behavioral changes. Fields at those levels are routinely encountered in the home around 60 Hz devices.) It was taken as a challenge to find a 1) highly sensitive but reliable behavioral assay that could, in principle, 2) detect thresholds and would allow 3) long exposure durations. For example, it seemed vain to think that five minutes of exposure to a 45 Hz field at 10 V/m would affect any behavior at all. A final requirement, based on repeated references in the literature to reaction time, circadian rhythms, etc., was that the task involve some kind of 4) "timing" behavior. These four requirements all seemed to be met by employing an interresponse time schedule of reinforcement (IRT task) in which an animal is reinforced for pressing a lever once very N sec within a specified period ("limited hold"). If the animal presses too early or too late, the timer recycles. In these studies, the animal was reinforced with a tiny squirt of apple juice for pressing the lever every 5 sec within a 2.5 sec limited hold. Exposures were four hours long and test periods were three hours long. In approximately 300 experiments, four 4-hour replications of each field exposure plus intermingled no-field tests were done for each of five monkeys. Evidence was discovered for a shift in the direction of shorted interresponse times in the presence of fields of a given frequency and voltage within a range from 1-100 V/m and 7 to 75 Hz.

Figure 1 shows the kind of IRT distributions that were observed for a single 4-hour exposure for a given field condition for one monkey and compares that distribution with a control, no-field test for the same monkey. Note the larger sample of responses in each distribution and the increasing separation of the distributions as voltage is increased from 1 to 56 V/m p-p.

Figure 2 summarizes the result of all of the experiments over all monkeys within the voltage range from 1 to 56 V/m p-p. The X-axis shows changes in average interresponse times, the Y-axis shows the three voltage levels tested (1, 10 and 56 V/m; the different bars represent frequencies tested). It may be seen that at 1 V/m, all differences are in the direction of shorted IRT's but none is statistically significant. At 10 V/m there is evidence for a threshold change for 7 Hz but not 45 Hz or 75 Hz. This may represent the biological relevance of this frequency; it is within the range of hippocampal theta for the monkey. At 56 V/m, IRT differences are much larger and significant for both 7 Hz and 75 Hz. Studies of EEG in two implanted monkeys in this series pointed towards a reduction of power in the range of 1-3 Hz and shift towards higher power in the middle EEG ranges of 5-16 Hz. Such data are compatible with heightened arousal and shorter IRT's.

Four major conclusions may be drawn from this study:

1) Frequency-specificity. The evidence for a low threshold for 7 Hz is most interesting. Analagous frequency-specificity changes in calcium efflux (6) in *in vitro* neonatal chick brains have been observed in our laboratory.

2) Voltage. The data suggest some degree of dose-dependency. Results at 100 V/m p-p were inconclusive and suggest either a voltage-window of the kind observed by Kalmijn (and in the calcium efflux studies) or a 24-hour carryover effect.

3) Duration of exposure. Relatively long exposure durations appear to have contributed to the systematic array of results.

4) Behavioral assay: The question of external stimulus control. The IRT task apparently was adequately sensitive and reliable. A comparison of our results with those of other negative primate studies revealed that in the negative studies, behavioral assays included more traditional tasks, including reaction time tests, fixed interval tests, match-to-sample tests, etc., typically administered in 15-minute intervals. Animals were deprived of food and water and exposed to a variety of light and sound cues regulating the various tasks. In the IRT task, the monkeys were isolated; they were not deprived during testing; there were no sound or light cues regulating their behavior. It might be said that the animals were forced, by the nature of the timing task, to pay attention to their own internal milieu.

A quick reminder note that this is quite analogous to Keeton's interpretation of the pigeon homing data. This general finding might be paraphrased as follows: behavioral effects, if any, of weak electric fields are more likely to be observed in the absence of strong external stimulus control.

A similar interpretation has been made in a number of studies in the area of behavioral toxicology. Figure 3 shows the results of a study (7) of the effects of amphetamine on a DRL (differential reinforcement of low rates) schedule of reinforcement. This schedule is similar to the IRT schedule, but lacks a limited hold. This schedule revealed a substantial effect of 1 mg/K of amphetamine on both number of responses and number of reinforcements. When the experiment was modified so that a single external stimulus cue (a light) was added to the onset of correct interval, the effects of amphetamine were completely obliterated.

Similarly, data from Laties (8) is presented in Figures 4 and 5. This study demonstrates that a pigeon worked on a FCN8 (fixed consecutive number) schedule of reinforcement showed extremely variable performance following administration of methyl mercury. However, the addition of a light cue, indicating when the animal should shift to the reinforcement key, resulted in "normalizing" his behavior so that the effects of the methyl mercury could no longer be observed.

The subsequent removal of the light revealed that the behavior once again appeared perturbed--and implied that the effects of the mercury were still present. Ogden Lindsley (8) has aptly labeled the use of such cues a "behavioral prostheses."

Finally, a similar example of the effect of external stimuli control was reported in a recent issue of the Journal of Comparative and Physiological Psychology by Braggio and Ellen (9). In studies of brain lesions in the septum, hippocampus, dorsomedial nuclei of the thalamus and dorsoventral thalamus they found that behavior on a DRL schedule is disrupted (over-responding occurs). The authors note that adding a light as a timing cue attenuated the symptom and "...eliminates the appearance of any difference between operated and normal animals during the cued training period" (p. 701).

The present series of studies utilized the methodological principles described above to assay possible behavioral and EEG changes associated with the presence of weak frequency-modulated ELF fields that closely simulated those of Project Seafarer. The techniques, description of the facilities, etc., have been described in detail in an earlier ONR Technical Report (Contract No. N0001469A02004037, April 1975) entitled "An Evaluation of Possible Effects of 45 Hz, 60 Hz and 75 Hz Electric Fields on Neurophysiology and Behavior of Monkeys. Phase 1: Continuous Wave" by R. Gavalas-Medici and S. R. Magdaleno.

II. METHODS

A. Field Simulation. Two double bronze screened exposure chambers were used. Parallel field plates (1 meter square) were spaced 50 centimeters apart in each chamber. A closed circuit TV camera was mounted inside each enclosure with monitor and equipment located outside. There were no AC devices inside the chambers except for the well-shielded camera and cables. All blowers, generators, etc., were kept outside the chamber. The rooms were illuminated with DC light. "Inside" and "outside" temperatures could be read remotely.

Monkeys were trained and tested in Foringer monkey chairs that had been modified so that as much metal as possible was eliminated (and replaced with specially fabricated plastic parts).

The frequency-modulated signal was generated by a special device designed and fabricated by IITRI. The frequency-modulated signal varied from 72 Hz to 80 Hz with a center frequency of 76 Hz. This frequency modulated field was tested at .2 V/m p-p, 10 V/m p-p and 56 V/m p-p. Additional testing was done with the same field with 10 V/m p-p of 60 Hz added on, to simulate the ambient 60 Hz field that might occur in the region of Project Seafarer. Other tests were made at 76 Hz CW so that possible effects could be compared with and without the frequency modulation. Tests at 7 Hz CW had been made in the 1975 studies and those results suggested a distinctly lower threshold for this biologically relevant frequency (it is within the range of hippocampal theta for the monkey).

The electric fields were measured before and after the experiments by IITRI, utilizing their specially developed high impedance electric field probe and magnetic field probe. The presence of the field was continuously monitored during testing. At the beginning of the experiments, this was done by recording the signal on the Grass EEG recorder (used to record EEG data from implanted monkeys). However, this produced a high-pitched, faintly audible noise from the recording pens when the higher frequencies (76 Hz, 76 mek) were used. Consequently, the presence of the field was monitored with an oscilloscope to prevent possible auditory detection of the field by the monkeys. This change in procedure resulted in the inadvertent grounding of one of the field plates and a resultant imbalance in the electric fields between the plates. Measurements and mapping of the field were made by ITTRI at the conclusion of the experiment.

The voltage levels in the center of the chamber were only slightly affected by the imbalance. Field levels were measured at ± 10% of the expected value in the region between the plates where the monkey was positioned.

Conducted current measurements in a phantom monkey indicated that these values were substantially higher in the imbalanced field than in the balanced field condition (e.g., 8.3 nanoamps at 10 V/m p-p vs. 0.35 nanoamps). The overall lack of significant behavioral changes described later in this report suggests that, in any case, these increased current values did not produce spurious false positive results.

A detailed description of the chambers and the field measurements is included in Appendix II ("Electromagnetic Field Measurements in Support of Primate Behavioral and EEG Studies" by Gauger, J.R. and Robertson, N.C.).

B. Experimental Design - Behavior. Behavioral protocols have been described in the ONR 1975 Technical Report and in related publications (see References at end of this report). The rationale for the use of the interresponse time schedule of reinforcement as a behavioral assay has been discussed in Appendix B, "Behavioral Assays of Possible Weak ELF Effects: Comments and Recommendations" in a 1977 report of the "Biologic Effects of Electric and Magnetic Fields Associated with Proposed Project Seafarer" by the National Research Council, National Academy of Sciences. (See Appendix III, this Report.)

Briefly, this schedule of reinforcement entails training the monkey to press a lever once every N sec (5 sec) within a specified time "window" (2.5 sec). As in the CW studies reported in 1975, animals were trained for approximately 100 days for three hours per day at the same time everyday until performance levels reached about

80% correct. Animals were maintained on a standard laboratory diet (monkey chow pellets, fruit and water) and correct responses on the IRT task were reinforced with small squirts of apple juice. Animals were tested in adapted Foringer monkey chairs five days a week and returned to their home cages over the weekend.

Six animals (two implanted with EEG electrodes and four implanted) were tested in a counterbalanced series of tests at 10 V/m p-p. One implanted animal died of causes unrelated to the experiment and the remaining five were tested at an array of frequencies at 56 V/m. Testing at 56 V/m and 10 V/m was counterbalanced for the five animals. At the conclusion of these experiments, four animals (two implanted and two unimplanted) were retrained to the criterion of 80% and then tested at .2 V/m p-p, a level chosen to correspond to field levels measured near the Project Seafarer antenna. Frequencies tested at all three voltage levels included 76 Hz frequency modulated, 76 Hz frequency modulated with 10 V/m p-p of 60 Hz added in, 76 Hz CW and 7 Hz CW. Control (no-field) tests were interspersed with field tests in a counterbalanced design and no-field "carry-over" tests followed every day of field exposure. Monday was routinely considered a practice day. In all cases, monkeys were exposed to the fields for four hours and tested in the behavioral task during hours two, three and four. On control tests, the animals simply sat in the chamber for one hour before testing began. The protocol for these experiments differed from the protocol for the CW studies in three ways: 1) "Carry-over" tests were done in this series of tests and not in the CW tests, 2) only two replications of each field condition were performed rather than four, 3) conditions were randomly assigned in the CW study and counterbalanced in the present study.

In addition, preliminary training of the monkeys was done in a modified version of the 7.5 sec IRT >5 sec task. An attempt was made to make the task more sensitive to possible field effects by pretraining the animals on an 18 sec <IRT>12 sec task and testing them on a 15 sec <IRT> 12 sec task. It was hypothesized that the relatively wide training "window" could allow the animals a larger margin of improvement (markedly shorter IRT's) under appropriate field conditions. However, this technique produced too much variability in responding and was discontinued. All animals were then retrained in the 7.5 sec <IRT>5 sec task used in the 1975 CW studies. This fact may be of special significance because IRT values were substantially smaller in the present study for all conditions, including control conditions, than in the CW study.

For all conditions behavioral data were recorded on an FR 1260 Ampex tape recorder. The analog tapes were digitized and then analyzed. Each response of the animal was tallied as a function of time elapsed since the immediately preceding response. Bin width for analysis was set at .1 sec and 175 bins were counted. Histograms were printed for the total three hour sessions and for consecutive 15-minute sessions. Means, medians, modes and standard deviations were routinely calculated for each experiment.

C. Experimental Design - EEG. Two of the animals were implanted with an array of bipolar EEG electrodes (see the April 1975 report for a complete description of techniques).

EEG data for all experiments at 10 V/m and 56 V/m were tape recorded, digitized and analyzed. Time did not allow for analysis of EEG data at .2 V/m. Data were sampled from the last hour of the experiment for a set of 12 or more correct and 12 or more incorrect responses.

The EEG data were analyzed from the end of the last response pulse to the onset of the correct or incorrect response pulse to be analyzed. Samples were drawn from the end of the exposure period. All available samples were used in the analysis with the exception of a few with obvious large movement artifacts. Spectral analysis was done for each response segment; resolution was set at 1 Hz and covered the range 1-32 Hz. The subsets of correct and incorrect responses were merged for each experiment and then merged across replications of a given field condition or a control condition. This resulted in a sample of approximately 24 or more correct and approximately 24 or more incorrect responses for each experimental condition and approximately 48 or more of each response for the control condition. These merged spectra were plotted as percentages of total power, in order to provide an index of possible changes in total power over time.

Brain structures assayed included for animal A: the right hippocampus, left hippocampus, and right amygdala at 10 V/m. At 56 V/m, the right amygdala and right and left centre median were recorded. For animal G: the right hippocampus, right superior colliculus, and right temporal lobe were recorded for both 10 and 56 V/m.

Because recordings were made from only two animals, no inferential statistics were calculated. Instead, the complete data set of percent power graphs is presented in Appendix I.

III. RESULTS

A. Behavior. Mean IRT's, standard deviations, number of responses, and percent correct are presented for each voltage level tested in Tables 1-6. In all cases, the mean IRT for each replication is weighted by the number of responses in that replication. The means and standard deviations therefore represent weighted means across replications for each condition for each animal. There is no obvious ordering of effects at .2 V/m p-p. It may be seen that the control condition (0/0 c) falls in rank 1 (the shortest IRT) in two cases and in ranks 3 and 4 in the other two cases.

At 10 V/m (Table 3) there is some indication of a possible effect for the 76 Hz frequency-modulated field (76 m) since the mean IRT for this condition falls in rank 1 for four of the six animals. However, this consistency is not apparent in the measurements of variability.

At 56 V/m it may be noted that the 7 Hz CW field is associated with a shorter-than-control mean IRT for each of the five animals. The associated standard deviation is smaller for four of the five animals.

Descriptive *t* statistics for no-field minus field mean IRT values across animals are presented in Table 7. It may be seen that the only statistically significant difference occurs at 10 V/m for the 76 Hz frequency-modulated condition. However, in view of the large array (15) of *t* tests and the lack of any effect at 56 V/m, this finding may well be due to chance. It is surprising that so many negative values appear for the .2 V/m tests. This may be due to the fact that this test series followed the others in time. The animals were exceedingly well trained at this point and their average control value was 5.25 sec as compared with a control value of 5.37 for the 56 V/m tests and 5.51 for the 10 V/m tests.

More positive differences appear at the higher voltage levels than the lower levels, suggesting some "dose dependency" in the array. The 7 Hz condition is associated with relatively large positive differences at 10 V/m and 56 V/m; these differences approach but do not reach statistical significance. This finding would seem to be in general agreement with the 1975 CW studies which indicated an effect for 7 Hz at 10 V/m and an even larger effect at 56 V/m (see Table 8). The robustness of these earlier findings may well be due to the greater number of replications (4 vs. 2) in the 1975 study. If the 10 V/m data for 7 Hz are combined across the two studies, the average difference is .082, the standard error is .044, and the *t* is 1.876 and significant at the .05 level (one-tailed). Similarly, if data for 7 Hz at 56 V/m p-p are combined across the two studies, $\bar{D}$ is .172, $S_{\bar{x}_1-\bar{x}_2}$ = .077, *t* is 2.234 and significant at the .01 level.

Extensive analysis of variance across different subsets of the present data set present no surprises.

A simple one-way analysis of variance within voltage levels (Table 9) reveals no significant F's at any level. The largest F is associated with frequency of the field at 10 V/m (f = 1.43) and reflects the *t* statistic reported for the 76 Hz frequency-modulated field at that level.

Two-way analyses of variance are shown in Table 10 where field frequency and the subgroups of implanted monkeys A and G versus unimplanted monkeys are considered within voltage levels. A relatively high F (7.88) occurs for implanted vs. unimplanted animals at the highest voltage level (56 v/m p-p). All means reveal that the two implanted monkeys have a longer IRT (5.514 sec) and the unimplanted have a shorter average IRT (5.294 sec).

Results of three-way analyses of variance (comparing field frequency, implanted vs. unimplanted and two voltage levels) are shown in Table 11.

No significant effects are observed for .2 V/m vs. 10 V/m or for .2 V/m vs. 56 V/m. When 10 V/m is contrasted with 56 V/m, a significant interaction is observed for field frequency and whether or not the monkey is implanted. This, again, reflects the fact that the two implanted animals appear to be relatively "slow" responders in this experiment. At 10 V/m, the average IRT for the 76 Hz modulated condition is 5.770 for implanted monkeys and 5.127 for unimplanted monkeys. The N's involved in these comparisons are very small (2 vs. 3 and 2 vs. 4). Therefore, these results should not be over-interpreted.

During the long test series, the field was inadvertently unbalanced, as described earlier. Two monkeys (A and G) had already been tested in the balanced field mode at 10 V/m and one monkey (J) had been tested in the balanced field at 56 V/m. As a precaution, some analyses of variance were done on the larger (unbalanced mode group) to be sure that this procedural change had not markedly affected performance. Table 12 summarizes these data. Data at .2 V/m are identical since all monkeys were run in the same mode. At 10 V/m p-p, field frequency produces a significant F (3.42). This undoubtedly reflects the shorter IRT's associated with the 76 Hz modulated field that were described earlier.

At 56 V/m, the analyses of variance results are approximately the same with or without the one balanced-field monkey included.

Additional analyses of variance were done with only those monkeys exposed to the unbalanced field. These results are similar to those observed when all animals are included in the analysis. A relatively high, but not significant, F is observed for implanted vs. unimplanted monkeys at 56 V/m, with implanted monkeys showing slower scores; this result also appeared in the complete data set.

In summary, the data at this point indicate that the frequency-modulated fields have no effect on monkeys' performance on the IRT task. A possible exception to this is suggested by the <u>t</u> test reported for the 76 Hz frequency-modulated field at 10 V/m. However, the lack of any other corroborating evidence makes it rather unlikely that this is more than a chance occurrence.

There is weak evidence for frequency specificity with relatively large field-control differences being observed for the 7 Hz condition, as they were in the 1975 study. The weakness of this effect may be due to the decreased number of replications (2 vs. 4) or it may be due to the overall faster performance of the monkeys in the present experimental series. Figure 6 shows a comparison of average control values and 7 Hz field values for the 1975 and 1978 studies. It is possible that the animals in the present study were performing close to an asymptotic level of performance (i.e., near the start of the reward period) so that further shortening of IRT's would cause the animal to begin to press too early and lose reinforcements. A rank order correlation of control IRT's and observed 7 Hz field-produce difference scores is shown in Table 14. When the 1975 and 1978 da are combined, the Rho is .62 and significant at the 0.5 level. Thi lends support to the notion that large field-produced differences could be less likely to be seen in the present series where animals had been extensively pretrained.

In a June 31, 1978 quarterly report, a series of studies on fiel related calcium efflux from neonatal chick brains (S. M. Bawin and W. R. Adey) have been described. As in the 1975 behavioral CW studi ELF frequencies within EEG range (6 and 16 Hz in the case of the chi 7 Hz for the monkey) resulted in statistically significant changes. For the monkeys, behavioral changes were observed at 7 Hz, 10 V/m and larger changes were observed at 7 Hz, 56 V/m. For the chicks, a significant decrease in calcium efflux was observed for 6 and 16 Hz at 10 V/m. Differences of about the same magnitude were observed at 56 V/m p-p (see Table 15).

Similar calcium studies were undertaken with the same array of frequency-modulated fields described in the present behavioral studies. The results are remarkably comparable to those observed with the IRT task. None of the modulated fields produced a significant effect on calcium efflux. The largest change observed was for the 76 Hz frequency-modulated field with voltage level set at 10 V/m (see Table 16). This field condition also resulted in the largest perturbation of behavior in the monkey studies.

B. <u>EEG Results</u>. In earlier studies, changes in hippocampal activity had been noted for some field conditions. In the present study, there is evidence for somewhat more activity in the 4-16 Hz range for both animals for all field conditions, relative to the control condition. This suggests a nonspecific heightened arousal during field exposure similar to that described in the 1975 study.

Behavioral changes in this study were observed during exposure to the 10 V/m 76 Hz frequency-modulated condition. The EEG graphs indicate a peak at about 4 Hz for Animal A (R. hippocampus) at 10 V/m. However, this peak does not appear for Animal G.

Other brain structures tested do not present marked changes during field exposure. Small changes relative to the control condition appear to be attributable to chance. They are not consistent across voltage levels nor across animals.

IV. SUMMARY AND CONCLUSIONS

A. <u>Frequency-Modulated Fields</u>. With one exception, none of the 76 Hz frequency-modulated fields (either with or without 10 V/m p-p of 60 Hz added on) produced any significant change in behavior as measured by an interresponse time schedule of reinforcement.

Voltage levels of .2 V/m, 10 V/m and 56 V/m p-p were assayed. The possible exception is a reduced interresponse time for the 76 Hz modulated field at 10 V/m p-p. However, the effect does not appear at either lower or higher voltage levels (see Figure 7) and, indeed, the observed difference is in the opposite direction in those tests. Furthermore, analyses of variance data at 10 V/m do not show a field frequency effect.

Data from the calcium efflux studies are remarkably compatible with the behavioral results. No significant changes are observed for any of the frequency-modulated fields at any voltage level. As in the monkey studies, the largest difference observed is for the 76 Hz frequency-modulated field at 10 V/m p-p.

Taken together, these data essentially present a picture of no effect for the frequency-modulated fields. The possibility of a borderline, nearthreshold effect at 10 V/m suggests that more testing (both behavioral and neurochemical) might be performed at that level. However, that is well above expected field levels around Project Seafarer (.2 V/m p-p).

B. CW Fields. An extensive series of studies on CW fields and interresponse time behavior was reported by this laboratory in 1975. These studies indicated a frequency-specific effect; namely, a low threshold for a CW field within EEG range of the performing monkey (see Figure 8). In the present study, the 7 Hz field produced relatively large positive changes at both 10 V/m p-p and 56 V/m p-p. These differences approached but did not achieve statistical significance. It has been suggested that 1) pretraining of the animals and 2) reduced number of replications may have lowered the value of the observed differences. If data are combined for the 1975 and 1978 studies, results remain significant at both voltage levels.

Studies of calcium efflux in neonatal chick brains, again, show a very good concordance with the behavioral results. Systematic decreases in calcium efflux were observed at 10 V/m p-p and 56 V/m p-p for EEG range CW field frequencies (6 Hz and 16 Hz) for the chicks.

In conclusion, both the behavioral and neurochemical studies suggest that the frequency-modulated fields are not likely to perturb behavior or calcium efflux at the frequencies and voltages tested. The maximal effect observed was a borderline change at 10 V/m p-p for the 76 Hz frequency-modulated field.

The CW studies interpreted in the context of the earlier studies (1970 and 1975) support the general hypothesis of frequency specificity and suggest that ELF fields that are biologically relevant; i.e., within EEG range, may have substantially lower thresholds than either CW fields outside that frequency range or frequency-modulated fields outside that range.

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Table 1.

ONR-MSK .2 V/m
RANK ORDER WEIGHTED MEAN IRT AND STANDARD DEVIATION
(Entire Experiment - Last Bin Excluded)

Animal A		Animal B		Animal J (u)		Animal N (u)	
Cond.	$\bar{X}$	Cond.	$\bar{X}$	Cond.	$\bar{X}$	Cond.	$\bar{X}$
76 M	5.14	0/0c	5.15	0/0c	5.46	76/60	5.09
76	5.17	76/60	5.18	0/0x	5.46	76M	5.11
0/0c	5.20	0/0x	5.20	7	5.46	0/0x	5.16
7	5.25	7	5.22	76	5.57	0/0c	5.18
0/0x	5.26	76M	5.22	76M	5.60	76	5.21
76/60	5.39	76	5.42	76/60	5.64	7	5.36

Cond.	σ	Cond.	σ	Cond.	σ	Cond.	σ
7	.83	0/0c	.80	0/0x	1.14	76M	.72
76M	.84	76M	.83	76M	1.30	76/60	.73
76	.91	0/0x	.90	0/0c	1.36	76	.85
0/0x	.97	7	.96	76/60	1.40	0/0x	.93
76/60	1.03	76	1.07	7	1.42	0/0c	.95
0/0c	1.04	76/60	1.10	76	1.52	7	1.30

(u) indicates unimplanted animal

Table 2.

ONR-MSK .2 V/m
RANK ORDER NUMBER OF RESPONSES (N)
AND PERCENT CORRECT (%)

Animal A		Animal J (u)		Animal N (u)		Animal G	
Cond.	N	Cond.	N	Cond.	N	Cond.	N
0/0x	1149	0/0x	605	0/0c	1689	0/0x	770
76	988	76	574	7660	1553	7	716
7	947	0/0c	434	76	1397	76M	704
76M	787	76M	402	76M	1330	0/0c	630
0/0c	780	7660	388	0/0x	1300	76	579
7660	734	7	385	7	870	7660	561

Cond.	%	Cond.	%	Cond.	%	Cond.	%
7660	88	0/0x	87	76	78	7	82
76	82	76M	84	76M	78	76M	81
7	81	76	81	0/0x	76	76	80
0/0c	81	0/0c	81	0/0c	72	0/0x	77
76M	80	7660	81	7	70	0/0x	77
0/0x	77	7	77	7660	69	7660	76

(u) indicates unimplanted animal

Table 3.

ONR-MSK 10 V/m
RANK ORDER WEIGHTED MEAN IRT AND STANDARD DEVIATION
(Entire Experiment - Last Bin Excluded)

Animal A		Animal G		Animal J(u)		Animal N(u)		Animal K(u)		Animal L(u)	
Cond.	X	Cond.	X	Cond.	X	Cond.	X	Cond.	X	Cond.	X
0/0m	5.88	76	5.29	76M	5.29	76M	5.19	76M	4.90	76M	5.3[illegible]
7	5.89	7	5.34	0/0x	5.34	0/0c	5.23	7660	5.01	7660	5.3[illegible]
76M	5.91	0/0x	5.37	0/0c	5.38	0.0x	5.26	0.0c	5.20	7	5.4[illegible]
0/0x	6.00	0/0m	5.45	7	5.41	7	5.27	0/0x	5.24	76	5.5[illegible]
0/0c	6.13	7660	5.55	7660	5.51	7660	5.28	7	5.33	0/0c	5.5[illegible]
7660	6.14	0/0c	5.62	76	5.57	76	5.31	76	5.36	0/0x	5.5[illegible]
76	6.26	76M	[illegible].63								

Cond.	σ	Cond.	σ	Cond.	σ	Cond.	σ	Cond.	σ	Cond.	σ
7	1.37	76	.89	76M	1.12	7	.75	76	1.55	7660	1.2
0/0c	1.55	7660	.99	0/0x	1.12	76M	.77	7	1.73	0/0x	1.3
0/0x	1.55	76M	1.08	0/0c	1.14	0/0c	.81	0/0c	1.80	0/0c	1.4
76	1.59	0/0x	1.11	7	1.24	76	.90	76M	1.85	76	1.5
76M	1.63	0/0m	1.11	7660	1.37	7660	.93	0/0x	1.86	76M	1.5
7660	1.64	7	1.17	76	1.55	0/0x	1.02	7660	1.99	7	1.5
0/0m	1.66	0/0c	1.25								

Legend

7 = 7 Hz
76 = 76 Hz CW
76M = 76 Hz frequency modulated
7660 = 76 Hz frequency modulated plus 60 Hz @ 10 V/m p-p
0/0m = Monday
0/0c = Control
0/0x = Carry-over day
u = unimplanted animal

Table 4.

ONR-MSK 10 V/m
RANK ORDER NUMBER OF RESPONSES (N) AND PERCENT CORRECT (%)
(Entire Experiment - Last Bin Included)

Animal A		Animal G		Animal J(u)		Animal N(u)		Animal K(u)		Animal L(u)	
Cond.	N	Cond.	N	Cond.	N	Cond.	N	Cond.	N	Cond.	N
76	445	7660	794	76	723	7660	1174	7660	825	76M	663
0/0x	512	76M	868	7	802	0/0c	1228	76	1061	0/0x	762
7	519	0/0c	374	0/0x	820	76	1232	0/0x	1112	7	807
0/0m	521	0/0m	985	0/0c	890	7	1245	0/0c	1240	7660	832
0/0c	540	0/0x	1196	7660	929	0/0x	1264	7	1241	76	838
76M	596	7	1201	76M	1080	76M	1332	76M	1982	0/0c	883
7660	631	76	1427								

Cond.	%	Cond.	%	Cond.	%	Cond.	%	Cond.	%	Cond.	%
76M	68	76	75	76M	67	76M	76	7660	62	7	70
7660	70	0/0x	77	7660	69	0/0x	77	76M	63	76M	75
0/0m	71	7	79	76	70	0/0c	78	76	65	7660	75
0/0c	79	0/0c	80	0/0x	70	76	80	0/0x	69	76	77
7	81	76M	81	0/0c	70	7	82	7	74	0/0c	78
76	83	7660	81								

Legend

7 = 7 Hz
76 = 76 Hz CW
76M = 76 Hz frequency modulated
7660 = 76 Hz frequency modulated plus 60 Hz @ 10 V/m p-p
0/0m = Monday
0/0c = Control
0/0x = Carry-over day
u = unimplanted animal

Table 5.

ONR-MSK 56 V/m
RANK ORDER WEIGHTED MEAN IRT AND STANDARD DEVIATION

Animal A		Animal G		Animal J(u)		Animal N(u)		Animal K(u)	
Cond.	$\bar{X}$	Cond.	$\bar{X}$	Cond.	$\bar{X}$	Cond.	$\bar{X}$	Cond.	$\bar{X}$
7660	5.34	0/0x	5.40	7	5.31	7660	5.18	7	5.15
0/0x	5.37	7	5.47	7660	5.32	7	5.21	76M	5.18
7	5.38	0/0c	5.49	0/0c	5.34	0/0c	5.21	76	5.20
76	5.42	76	5.63	76	5.35	76	5.25	0/0x	5.20
76M	5.50	7660	5.75	0/0x	5.42	76M	5.26	0/0x	5.43
0/0c	5.61	76M	5.81	76M	5.44	0/0x	5.28	7660	5.51
		0/0m	5.45						

Cond.	σ	Cond.	σ	Cond.	σ	Cond.	σ	Cond.	σ
7	.75	0/0x	.89	76	.74	7	.65	7	1.52
76M	.81	0/0c	.93	7	.77	0/0c	.71	0/0c	1.69
0/0x	.87	76	1.02	0/0c	1.02	76M	.71	76	1.71
0/0c	1.15	7	1.16	7660	1.10	76	.76	7660	1.71
7660	1.19	76M	1.22	0/0x	1.12	7660	.80	76M	1.79
76	1.23	7660	2.05	76M	1.15	0/0x	.85	0/0x	1.81
				0/0m	1.29				

Table 6.

ONR-MSK 36 V/m
RANK ORDER NUMBER OF RESPONSES (N) AND PERCENT CORRECT (%)

Animal A		Animal G		Animal J(u)		Animal N(u)		Animal K(u)	
Cond.	N	Cond.	N	Cond.	N	Cond.	N	Cond.	N
76M	516	76M	240	76M	1187	0/0x	984	76M	1349
7	593	7	515	0/0m	1302	76	1067	7660	1357
7660	602	7660	582	7	1320	7660	1206	0/0c	1425
76	634	76	797	0/0x	1490	76M	1295	0/0x	1477
0/0c	638	0/0x	886	0/0c	1556	0/0c	1346	76	1557
				7660	1591				

Animal A		Animal G		Animal J(u)		Animal N(u)		Animal K(u)	
Cond.	%	Cond.	%	Cond.	%	Cond.	%	Cond.	%
7660	80	7660	64	7660	66	76	78	76M	66
76	82	76M	76	0/0m	67	7660	78	0/0c	67
0/0x	85	7	79	0/0c	69	7	79	7	68
0/0c	87	0/0x	79	0/0x	73	0/0c	79	76	68
76M	88	0/0c	81	7	73	0/0x	81	7660	70
7	89	76	84	76M	73	76M	86	0/0x	70
				76	77				

Table 7.

DESCRIPTIVE t STATISTICS ACROSS FREQUENCIES
(No-field IRT $(\bar{X}_1)_{sec}$ - Field IRT $(\bar{X}_2)_{sec}$)

(Two-tailed tests used for all negative differences)

		.2 V/m	10 V/m	56 V/m
7 Hz	$\bar{D}$	- .075	.075	.066
	$S_{\bar{X}_1-\bar{X}_2}$	.038	.068	.042
	t	1.975	1.105	1.587
	p	$.20<p>.10$	$.20<p>.15$	$.10<p>.05$
76 Hz	$\bar{D}$	- .095	- .028	0.0
	$S_{\bar{X}_1-\bar{X}_2}$	.065	.034	
	t	1.462	.826	
	p	$.30<p>.20$	$.50<p>.40$	N.S.
76 Hz Mod.	$\bar{D}$	- .020	.138	- .067
	$S_{\bar{X}_1-\bar{X}_2}$	.051	.049	.072
	t	.391	2.816	.917
	p	$.80<p>.70$	$.05<p>.01$*	.50 p .40
76 Hz Mod. + 60 Hz	$\bar{D}$	- .078	.037	.050
	$S_{\bar{X}_1-\bar{X}_2}$	.069	.089	.106
	t	1.161	.410	.470
	p	$.40<p>.30$	$.35<p>.30$	$.35<p>.30$
Carry-over	$\bar{D}$	- .023	.057	.010
	$S_{\bar{X}_1-\bar{X}_2}$	.019	.047	.081
	t	1.165	1.217	.124
	p	$.40<p>.30$	$.15<p>.10$	$p>.90$

Table 8.

DESCRIPTIVE t-STATISTICS ACROSS VOLTAGE LEVELS AND FREQUENCIES
(No-field minus field)

	1 V/m		10 V/m		56 V/m		100 V/m	
	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
7Hz								
Size of diff.	.070	.012	.118	.160	.288	.178	-.060	.063
t	1.0174	.1232	2.4738	3.0769	2.2749	5.0712	.6543	.5224
p	<.20	<.50	<.05	<.025	<.05	<.01	<.30	<.35
45 Hz								
Size of diff.	.55	-.28	.55	-.10	---	---	---	---
t	.4074	.2692	.9016	.2439	---	---	---	---
p	<.40	<.45	<.25	<.45	---	---	---	---
60 Hz								
Size of diff.	---	---	---	---	-.003	.058	.023	.153
t	---	---	---	---	.0401	2.0939	.1756	1.7172
p	---	---	---	---	<.50	<.10	<.45	<.20
75 Hz								
Size of diff.	.094	-.020	0	-.012	.290	.225	-.088	.078
t	1.5285	.31	---	.1132	4.0111	3.2562	1.0693	1.2012
p	<.15	<.40	---	<.50	<.025	<.025	<.20	<.20

Table 9.

ONE-WAY ANALYSIS OF VARIANCE WITHIN VOLTAGE LEVELS

ANALYSIS OF VARIANCE FOR 1-ST DEPENDENT VARIABLE - X(1) X(2) X(3) X(4) X(5) X(6)

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
.2 V/m	Mean	673.10027	1	673.10027	4444.70	0.0000
p-p	Error	0.45432	3	0.15144		
	Field Frequency	0.03018	5	0.00604	0.67	0.6520
	Error	0.13508	15	0.00901		

ANALYSIS OF VARIANCE FOR 1-ST DEPENDENT VARIABLE - X(3) X(4) X(5) X(6) X(7) X(8)

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
10 V/m	Mean	107.82407	1	1076.82407	1864.53	0.0000
p-p	Error	2.88766	5	0.57753		
	Field Frequency	0.10826	5	0.02165	1.43	0.2476
	Error	0.37816	25	0.01513		

ANALYSIS OF VARIANCE FOR 1-ST DEPENDENT VARIABLE - X(1) X(2) X(3) X(4) X(5) X(6)

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
56 V/m	Mean	868.97757	1	868.97757	7205.25	0.0000
p-p	Error	0.48241	4	0.12060		
	Field Frequency	0.05624	5	0.01125	0.84	0.5395
	Error	0.26903	20	0.01345		

TABLE 10.

TWO-WAY ANALYSIS OF VARIANCE: FIELD FREQUENCY AND IMPLANTED VS. UNIMPLANTED ACROSS VOLTAGE LEVELS

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
ANALYSIS OF VARIANCE FOR 1-ST DEPENDENT VARIABLE - X(3) X(4) X(5) X(6) X(7) X(8)						
.2 V/m	Mean	673.10027	1	673.10027	3733.57	0.0003
	G - (I) vs. (U)	0.09375	1	0.09375	0.52	0.5457
	Error	0.36057	2	0.18028		
	H - Field Frequency	0.03018	5	0.00604	0.48	0.7810
	HG	0.01035	5	0.00207	0.17	0.9695
	Error	0.12473	10	0.01247		
ANALYSIS OF VARIANCE FOR 1-ST DEPENDENT VARIABLE - X(3) X(4) X(5) X(6) X(7) X(8)						
10 V/m	Mean	982.94376	1	982.94376	2917.51	0.2494
	G - (I) vs. (U)	1.54001	1	1.54001	4.57	0.0993
	Error	1.34765	4	0.33691		
	H - Field Frequency	0.09099	5	0.01820	1.45	0.2494
	HG	0.12748	5	0.02550	2.03	0.1172
	Error	0.25068	20	0.01253		
ANALYSIS OF VARIANCE OF 1-ST DEPENDENT VARIABLE - (X3) X(4) X(5) X(6) X(7) X(8)						
56 V/m	Mean	841.06112	1	841.06112	18963.75	0.0000
	G - (I) vs. (U)	0.34936	1	0.34936	7.88	0.0675
	Error	0.13305	3	0.04435		
	H - Field Frequency	0.06492	5	0.01298	1.07	0.4134
	HG	0.08763	5	0.01753	1.45	0.2638
	Error	0.18140	15	0.01209		

Legend -
(I) = Implanted
(U) = Unimplanted

Table 11.

THREE-WAY ANALYSIS OF VARIANCE: VOLTAGE LEVEL, FIELD FREQUENCY, IMPLANTED VS. UNIMPLANTED

.2 vs. 10 V/m - no significant effects
.2 vs. 56 V/m - no significant effects

10 V/m vs. 56 V/m:

ANALYSIS OF VARIANCE FOR 1-ST DEPENDENT VARIABLE - X(3) X(4) X(5) X(6) X(7) X(8) X(12) X(13) X(14)

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
Mean	1718.93923	1	1718.93923	10601.79	0.0000
I - Implanted vs. unimplanted	1.76540	1	1.76540	10.89	0.0457
Error	0.48641	3	0.16214		
Voltage Level	0.19928	1	0.19928	0.69	0.4683
VI	0.24284	1	0.24284	0.84	0.4280
Error	0.87178	3	0.29059		
H - Field Frequency	0.07364	5	0.01473	1.30	0.3171
HI	0.16634	5	0.03327	2.93	0.0486
Error	0.17047	15	0.01136		
VH	0.07591	5	0.01518	0.98	0.4609
VHI	0.05463	5	0.01093	0.71	0.6279
Error	0.23213	15	0.01548		

10 V/m: IRT $\overline{X}$, 76 Modl., implanted = 5.770
IRT $\overline{X}$, 76 Modl., unimplanted = 5.127

Table 12.

ANALYSIS OF VARIANCE FOR ANIMALS EXPOSED TO UNBALANCED FIELD MODE

.2 V/m same as Table 9. All monkeys tested in unbalanced mode.

10 V/m (Monkeys A & G omitted):

ANALYSIS OF VARIANCE FOR 1-ST DEPENDENT VARIABLE - X(1) X(2) X(3) X(4) X(5) X(6)

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
Mean	680.00251	1	680.00251	6725.02	0.0000
Error	0.30335	3	0.10112		
H - Field Frequency	0.14377	5	0.02875	3.42	0.0291
Error	0.12598	15	0.00840		

56 V/m (Monkey J omitted):

ANALYSIS OF VARIANCE FOR 1-ST DEPENDENT VARIABLE - X(1) X(2) X(3) X(4) X(5) X(6)

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
Mean	695.94958	1	695.84958	4334.50	0.0000
Error	0.48161	3	0.16054		
H - Field Frequency	0.05417	5	0.01083	0.64	0.6755
Error	0.25541	15	0.01703		

Table 13.

SPEARMAN RANK-ORDER CORRELATION COEFFICIENT BETWEEN CONTROL IRT's AND CONTROL-7 Hz MEAN IRT DIFFERENCE SCORES (CW and Present Studies Combined)

Animal	Mean Control IRT's	Rank	Diff. Scores	Rank	D	D^2
K (u)	5.20	1	-.13	1	0	0
N (u)	5.23	2	-.04	3	1	1
J (u)	5.37	3	-.08	2	1	1
E (u)*	5.44	4	.01	5	1	1
L (u)	5.53	5	.13	7	2	4
D*	5.58	6	.21	9	3	9
G	5.62	7	.28	11	4	16
B*	5.87	8	.15	8	0	0
C (u)*	6.03	9	.00	4	5	25
A	6.13	10	.23	10	0	0
A*	6.58	11	.12	6	5	25

Rho = .62
N = 11, p = .05

*From 1976 CW study

Table 14.

ASYMPTOTIC PERFORMANCE: Comparison of 1976 (N=5) and 1978 (N=6) Control Values in 10 V/m Study (Mann-Whitney U-Test)

1976 Mean IRT	U-Rank	1978 Mean IRT	U-Rank
6.58	11	6.13	10
6.03	9	5.62	7
5.87	8	5.53	5
5.58	6	5.38	3
5.44	4	5.23	2
		5.20	1

U = 7; P = .089

1976 σ	U-Rank	1978 σ	U-Rank
1.73	10.5	1.73	10.5
1.28	7	1.54	9
1.13	3.5	1.37	8
1.13	3.5	1.24	6
0.89	2	1.15	5
		0.75	1

U = 11; P = .268

Table 15.
ONR-MSK

EFFECTS OF ELF FIELDS ON $^{45}Ca^{2+}$ EFFLUX FROM THE CHICK FOREBRAIN

		m ± SEM (Field)	m ± SEM (Control)	No. Paired Samples	t	P
5 V/m	6 Hz	0.923 ± 0.036	1.000 ± 0.036	30	1.450	NS
	16 Hz	0.933 ± 0.041	1.000 ± 0.041	27	1.144	NS
	32 Hz	0.945 ± 0.041	1.000 ± 0.041	27	0.974	NS
10 V/m	1 Hz	0.943 ± 0.041	1.000 ± 0.038	26	1.021	NS
	6 Hz	0.866 ± 0.029	1.000 ± 0.037	26	3.069	<0.01
	16 Hz	0.849 ± 0.026	1.000 ± 0.031	38	3.726	<0.01
	32 Hz	0.913 ± 0.038	1.000 ± 0.037	27	1.633	NS
56 V/m	1 Hz	1.028 ± 0.042	1.000 ± 0.038	26	0.515	NS
	6 Hz	0.882 ± 0.031	1.000 ± 0.030	37	2.681	<0.05
	16 Hz	0.889 ± 0.035	1.000 ± 0.034	36	2.489	<0.05
	32 Hz	0.942 ± 0.038	1.000 ± 0.038	26	1.518	NS
100 V/m	6 Hz	0.928 ± 0.028	1.000 ± 0.029	36	1.735	NS
	16 Hz	0.995 ± 0.037	1.000 ± 0.037	28	0.092	NS

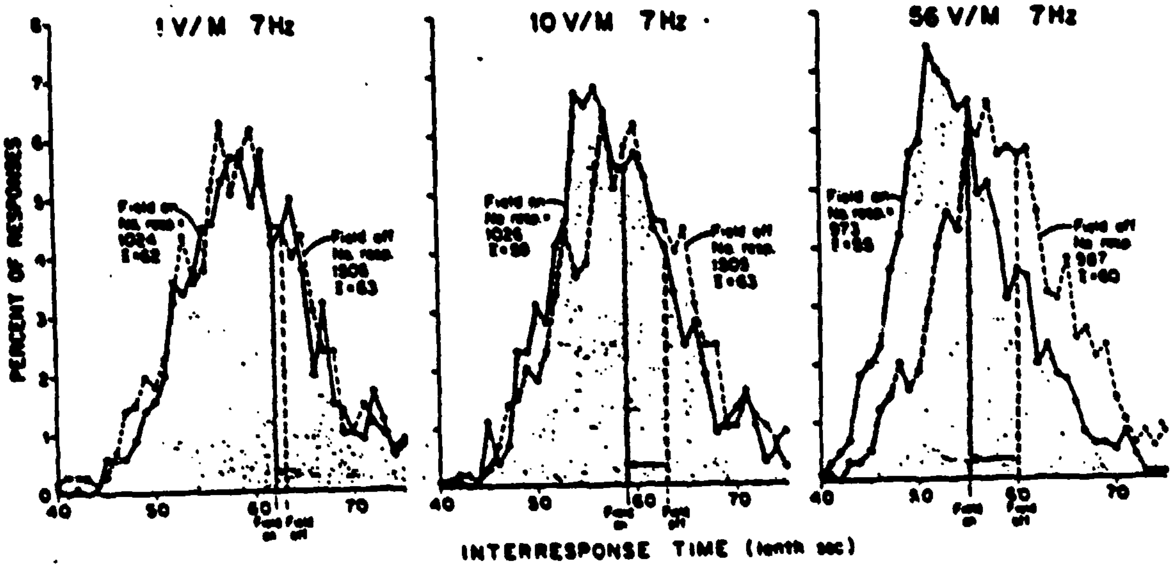
Table 16.

ONR-MSK

EFFECTS OF ELF FIELDS ON $^{45}Ca^{2+}$ EFFLUX FROM THE CHICK FOREBRAIN

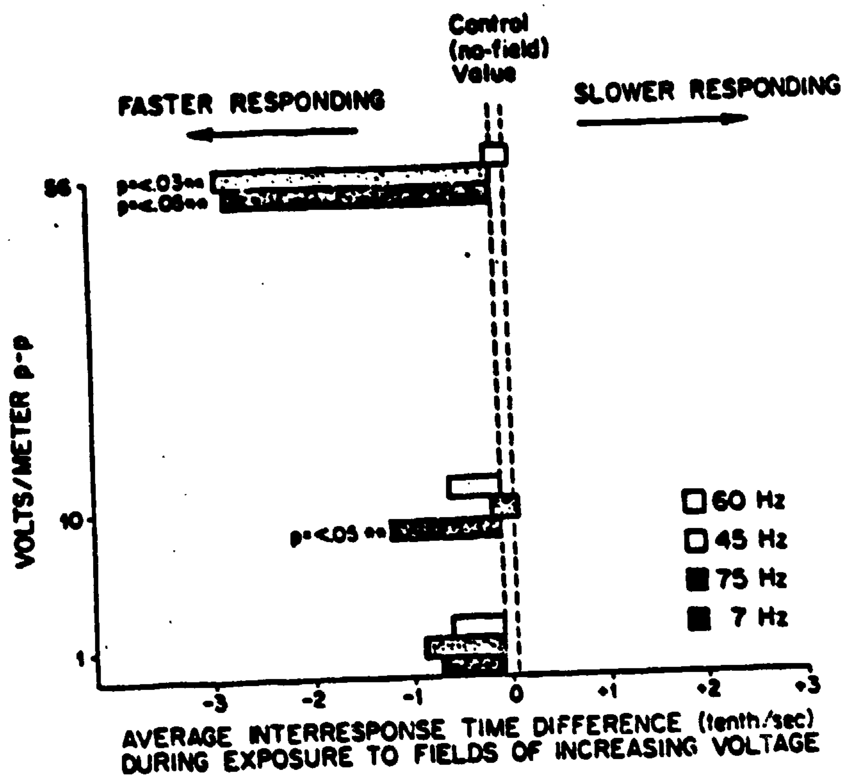
Field	m ± SEM (Field)	m ± SEM (Control)	No. of Paired Samples	t	p
76/10	1.054 ± 0.037	1.000 ± 0.027	49	1.184	NS
7660/10	1.034 ± 0.038	1.000 ± 0.028	46	0.710	NS
76/56	1.008 ± 0.036	1.000 ± 0.031	47	0.168	NS
7660/56	0.982 ± 0.032	1.000 ± 0.030	48	0.411	NS
16/10	0.888 ± 0.019	1.000 ± 0.026	73	3.560	.01

FIGURE 1.



IRT (interresponse time) histograms are shown for a single subject (*Macaca nemestrina*) are shown for field (filled circles) and no-field, control, (open circles) sessions at 1, 10 and 56 V/m p-p with a 7 Hz modulation frequency. Each histogram was constructed from the data from a single experimental session. The vertical bars indicate the means of each distribution. Reproduced from (5).

FIGURE 2.



The average IRT difference between field and control sessions is plotted as a function of field strength in V/m. Reproduced from (5).

FIGURE 3.

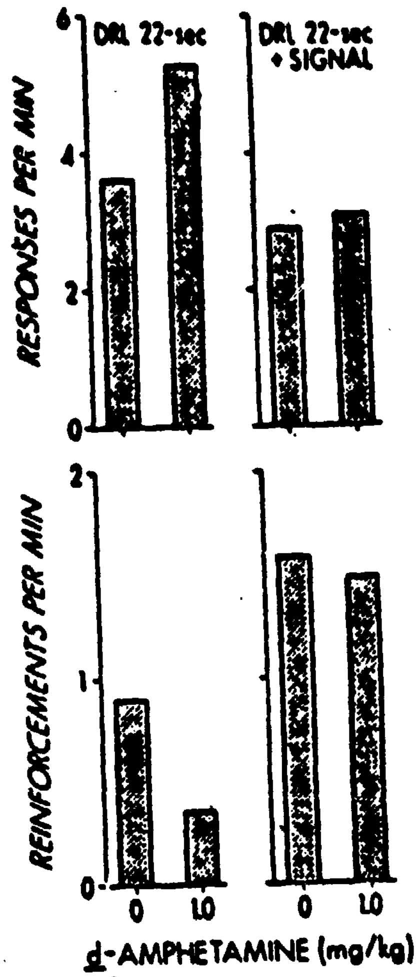
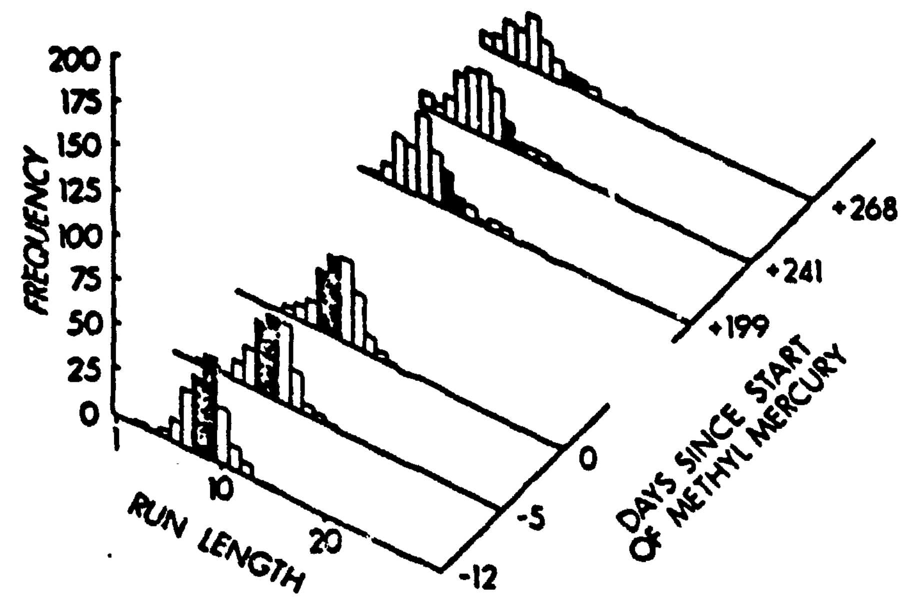


Figure 11. Effects of d-amphetamine on response rate (top panels) and reinforcement rate (bottom panels) of rats on DRL 22-sec schedules of reinforcement. The right panels summarize data collected when a change in external stimulation was correlated with the end of each 22-sec pause without responding. The left panels summarize data collected when no such change occurred. (Constructed from data in Carey and Kritkausky (3).)

The effects of external stimulus control, in the form of a "behavioral prosthesis," on performance on a DRL schedule are illustrated. The effects of the administration of d-amphetamine are abolished when the external stimulus indicating reinforcement availability is introduced. Reproduced from (8).

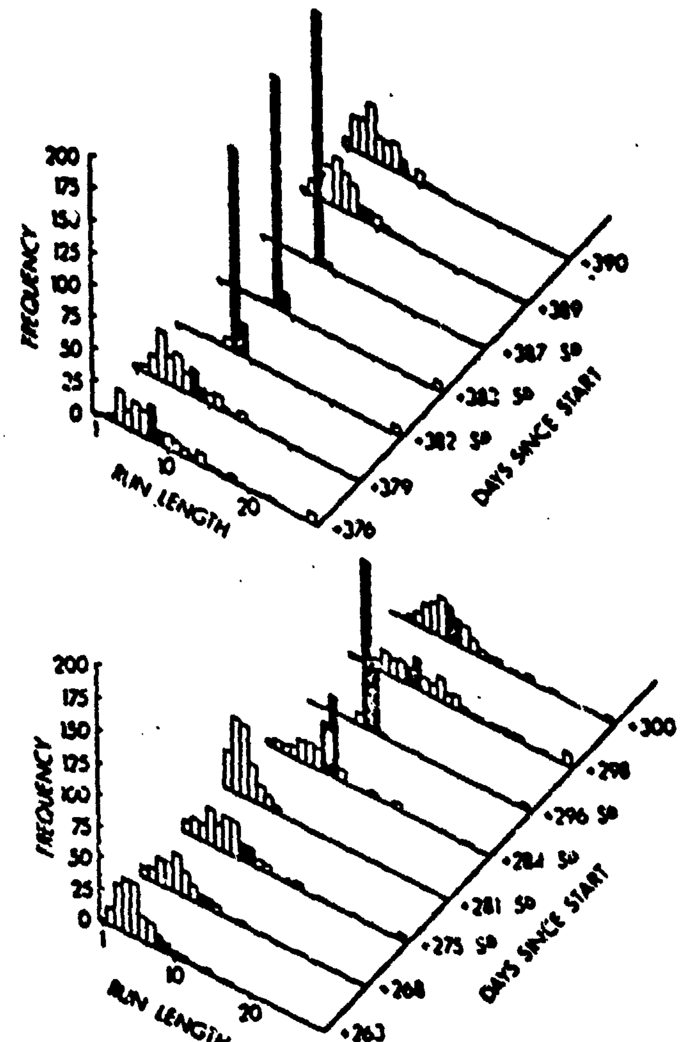
FIGURE 4.

Effects of methylmercury on the performance of a pigeon working on a fixed-consecutive-number (FCN) schedule in which only runs of eight and nine responses served to make possible reinforcement for a single response on a second key. (No stimulus change was correlated with these, or any other, run lengths.) The dark bars indicate reinforced runs. Four 200-run sessions occurred each week. Dosage regimen: 2.5 mg Hg/kg by mouth daily Monday through Friday for 2 wk and 2.2 mg Hg/kg Monday and Friday thereafter.



The effects of methyl mercury on pigeons working on an FCN 8 or 9 schedule. Reproduced from (8), data from (7).

FIGURE 5.



Changes induced in run length distributions by the addition of a discriminative stimulus (S^D). This stimulus was present after the eighth and before the tenth response on the FCN schedule of reinforcement during sessions labelled "S^D." During other sessions, no stimulus was correlated with any response runs. In all cases, only run lengths of eight or nine were reinforced; these are indicated by the dark bars.

The effects of an external discriminative stimulus (S^D) on performance on an FCN or 9 schedule following administration of methyl mercury. In this extension of Figure 4, it can be seen that the introduction of an external discriminative stimulus leads to the abolition of the measured effects of the methyl mercury and the removal of the external discriminative stimulus leads to their reappearance. Reproduced from (8).

FIGURE 6.

Comparison of 1978 and 1975 IRT Values For Control Tests and 7 Hz, 10 V/M Tests.

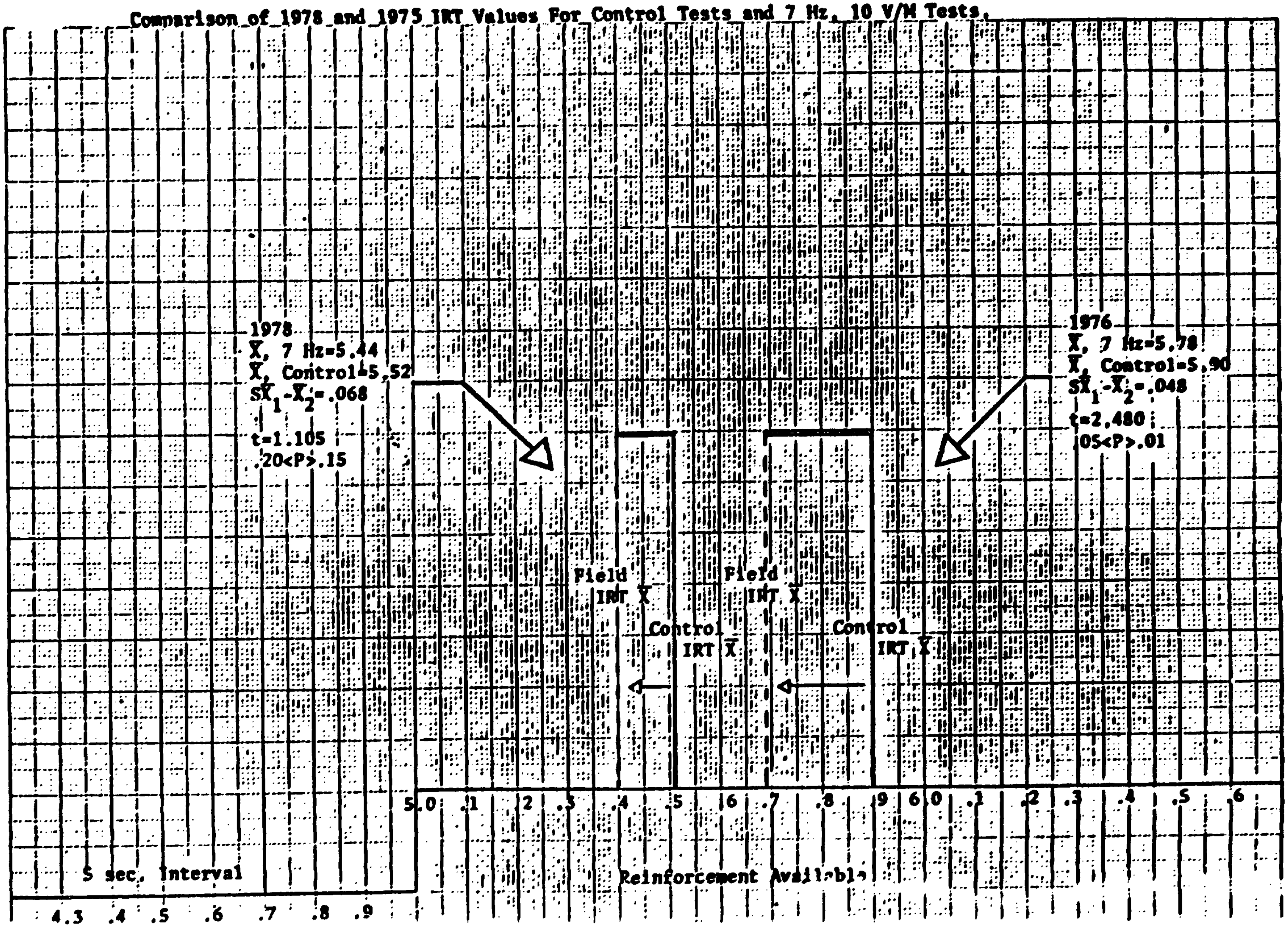


Figure 7.

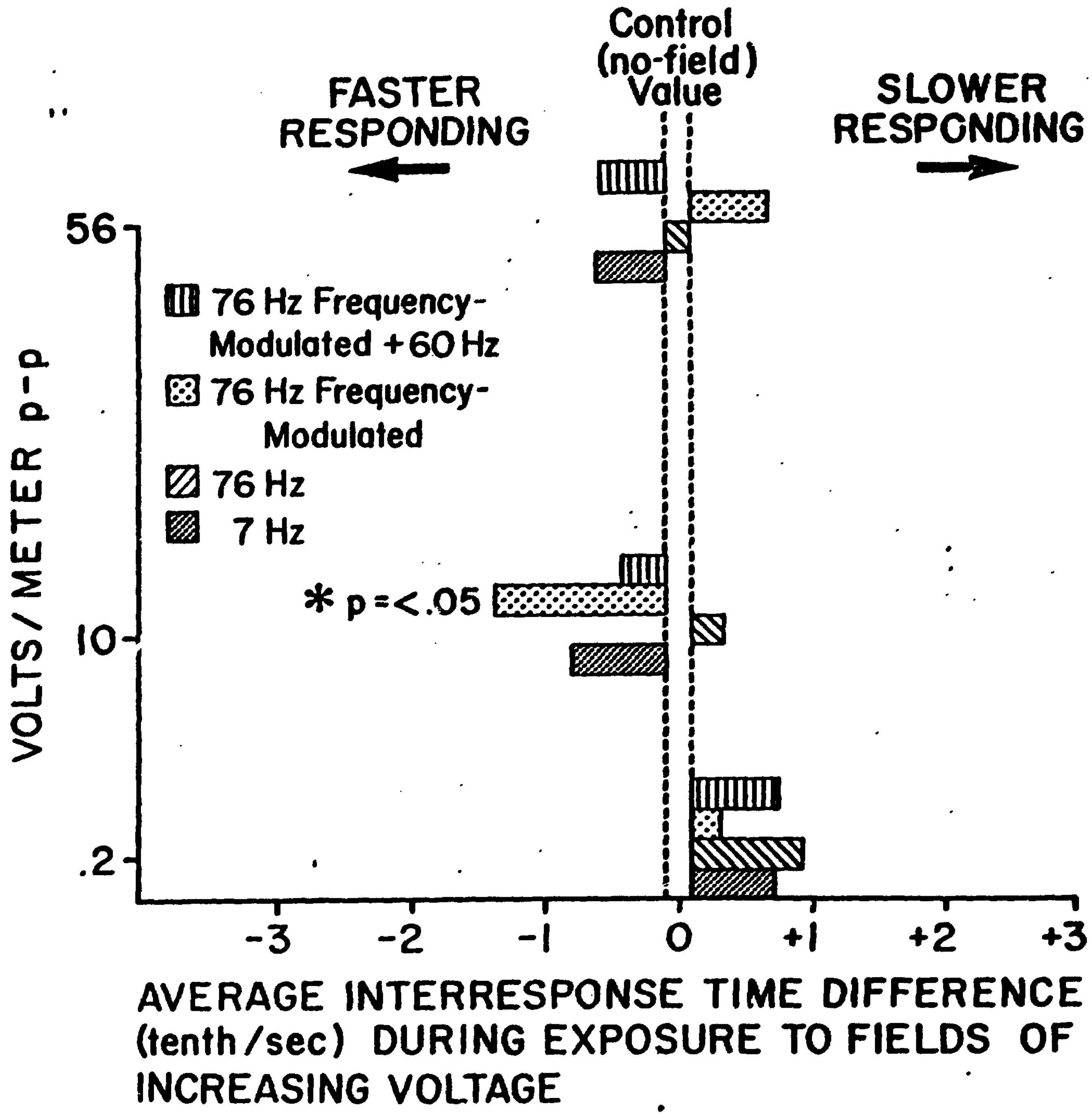
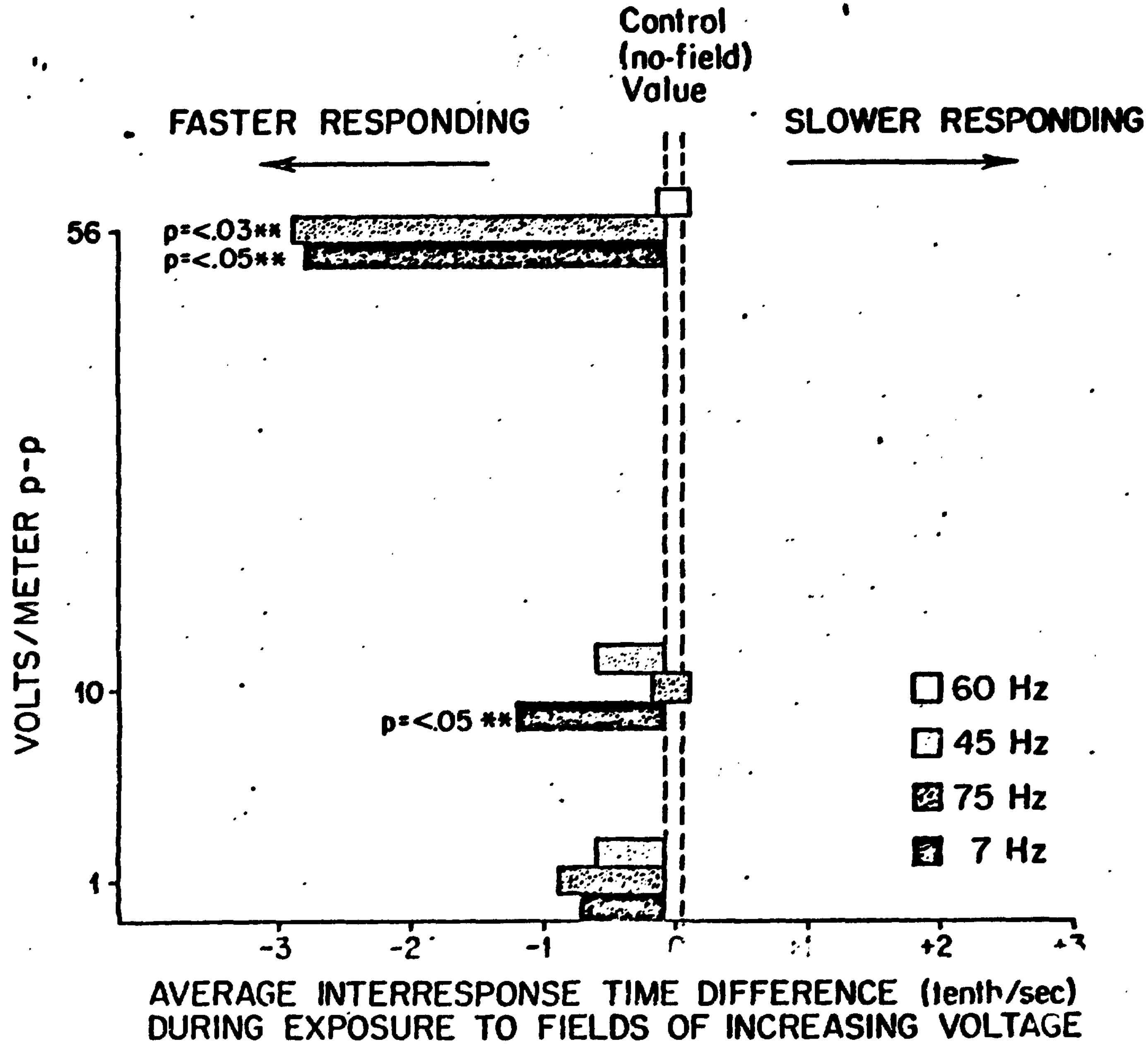

Control
(no-field)
Value
FASTER
RESPONDING
SLOWER
RESPONDING
56
10
.2
VOLTS/METER p-p
76 Hz Frequency-
Modulated +60 Hz
76 Hz Frequency-
Modulated
76 Hz
7 Hz
* p=<.05
-3
-2
-1
0
+1
+2
+3
AVERAGE INTERRESPONSE TIME DIFFERENCE
(tenth/sec) DURING EXPOSURE TO FIELDS OF
INCREASING VOLTAGE

Figure 8.



Control
(no-field)
Value
FASTER RESPONDING
SLOWER RESPONDING
p=<.03**
p=<.05**
p=<.05 **
VOLTS/METER p-p
56
10
1
60 Hz
45 Hz
75 Hz
7 Hz
-3
-2
-1
+2
AVERAGE INTERRESPONSE TIME DIFFERENCE (tenth/sec)
DURING EXPOSURE TO FIELDS OF INCREASING VOLTAGE

APPENDIX I.

EEG POWER SPECTRA

		Page
Animal A.	**R. Hippocampus**	
	Control: Correct, Incorrect 10 V/m Series	1
	7 Hz: Correct, Incorrect 10 V/m Series	2
	76 Hz: Correct, Incorrect, 10 V/m Series	3
	MSK (76 Hz, frequency-modulated): Correct, Incorrect 10 V/m Series	4
	MSK + 60 Hz: Correct, Incorrect 10 V/m Series	5
	L. Hippocampus	
	Control: Correct, Incorrect 10 V/m Series	6
	7 Hz: Correct, Incorrect 10 V/m Series	7
	76 Hz: Correct, Incorrect 10 V/m Series	8
	MSK (76 Hz, frequency-modulated): Correct, Incorrect 10 V/m Series	9
	MSK + 60 Hz: Correct, Incorrect 10 V/m Series	10
	R. Amygdala	
	Control: Correct, Incorrect 10 V/m Series	11
	Control: Correct, Incorrect 56 V/m Series	12
	7 Hz: Correct, Incorrect 10 V/m Series	13
	7 Hz: Correct, Incorrect 56 V/m Series	14
	76 Hz: Correct, Incorrect 10 V/m Series	15
	76 Hz: Correct, Incorrect 56 V/m Series	16
	MSK: Correct, Incorrect 10 V/m Series	17
	MSK: Correct, Incorrect 56 V/m Series	18
	MSK + 60 Hz: Correct, Incorrect 10 V/m Series*	
	MSK + 60 Hz: Correct, Incorrect 56 V/m Series	19
	RCM	
	Control: Correct, Incorrect 56 V/cm Series	20
	7 Hz: Correct, Incorrect 56 V/m Series	21

*Data lost.

76 Hz: Correct, Incorrect 56 V/m Series 22
MSK: Correct, Incorrect 56 V/m Series 23
MSK + 60 Hz: Correct, Incorrect 56 V/m Series 24

LCM
Control: Correct, Incorrect 56 V/m Series 25
7 Hz: Correct, Incorrect 56 V/m Series 26
76 Hz: Correct, Incorrect 56 V/m Series 27
MSK: Correct, Incorrect 56 V/m Series 28
MSK + 60 Hz: Correct, Incorrect 56 V/m Series 29

Animal G. R. Hippocampus
Control: Correct, Incorrect 10 V/m Series 30
Control: Correct, Incorrect 56 V/m Series 31
7 Hz: Correct, Incorrect 10 V/m Series 32
7 Hz: Correct, Incorrect 56 V/m Series 33
76 Hz: Correct, Incorrect 10 V/m Series 34
76 Hz: Correct, Incorrect 56 V/m Series 35
MSK: Correct, Incorrect 10 V/m Series 36
MSK: Correct, Incorrect 56 V/m Series 37
MSK + 60 Hz: Correct, Incorrect 10 V/m Series 38
MSK + 60 Hz: Correct, Incorrect 56 V/m Series 39

R. Superior Colliculus
Control: Correct, Incorrect 10 V/m Series 40
Control: Correct, Incorrect 56 V/m Series 41
7 Hz: Correct, Incorrect 10 V/m Series 42
7 Hz: Correct, Incorrect 56 V/m Series*
76 Hz: Correct, Incorrect 10 V/m Series 43
76 Hz: Correct, Incorrect 56 V/m Series 44
MSK: Correct, Incorrect 10 V/m Series 45
MSK: Correct, Incorrect 56 V/m Series 46
MSK + 60 Hz: Correct, Incorrect 10 V/m 47

*Data Lost.

R. Temporal Lobe

Control: Correct, Incorrect 10 V/m Series 48

Control: Correct, Incorrect 60 V/m Series 49

7 Hz: Correct, Incorrect 10 V/m Series 50

7 Hz: Correct, Incorrect 56 V/m Series 51

76 Hz: Correct, Incorrect 10 V/m Series 52

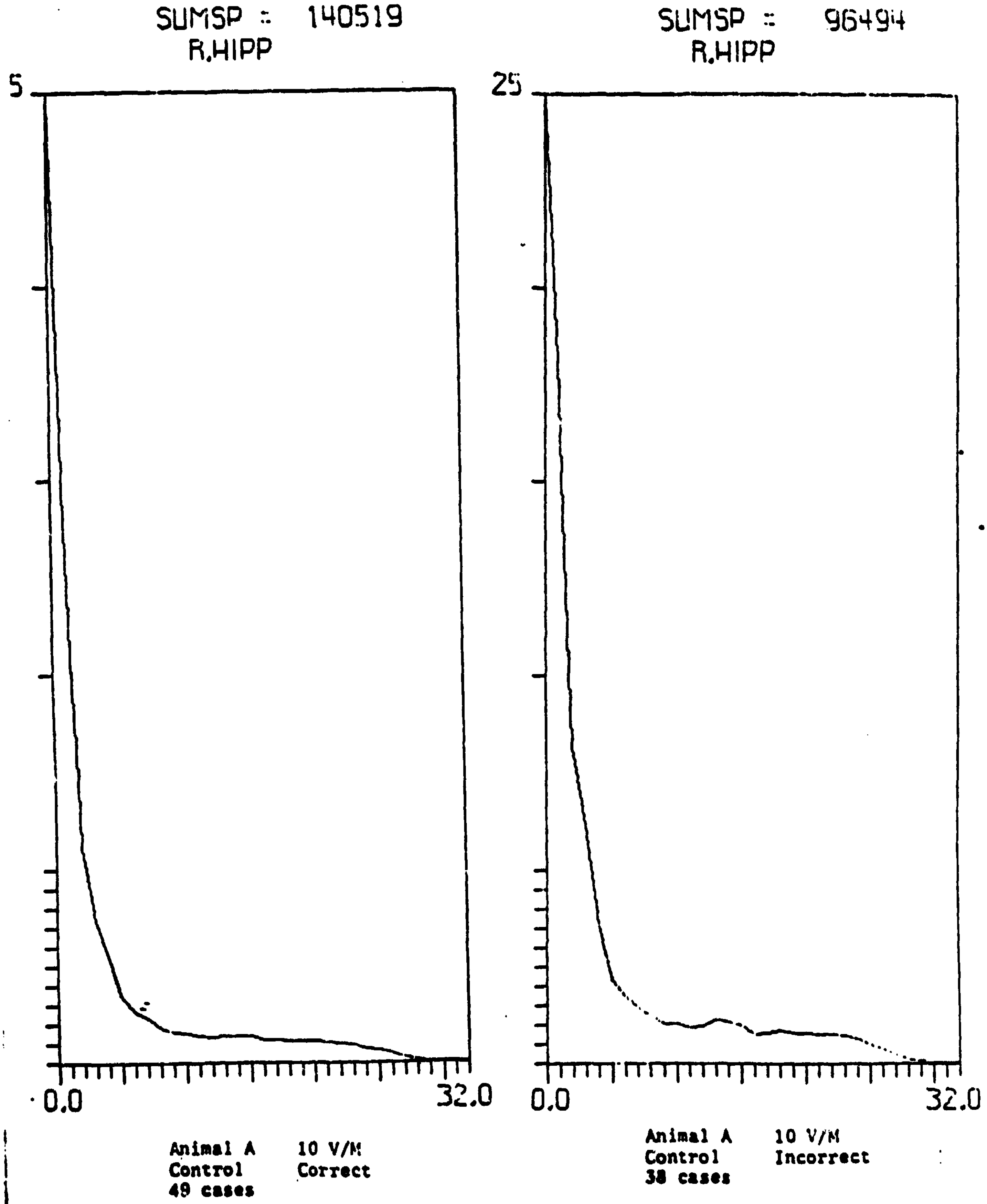
76 Hz: Correct, Incorrect 56 V/m Series 53

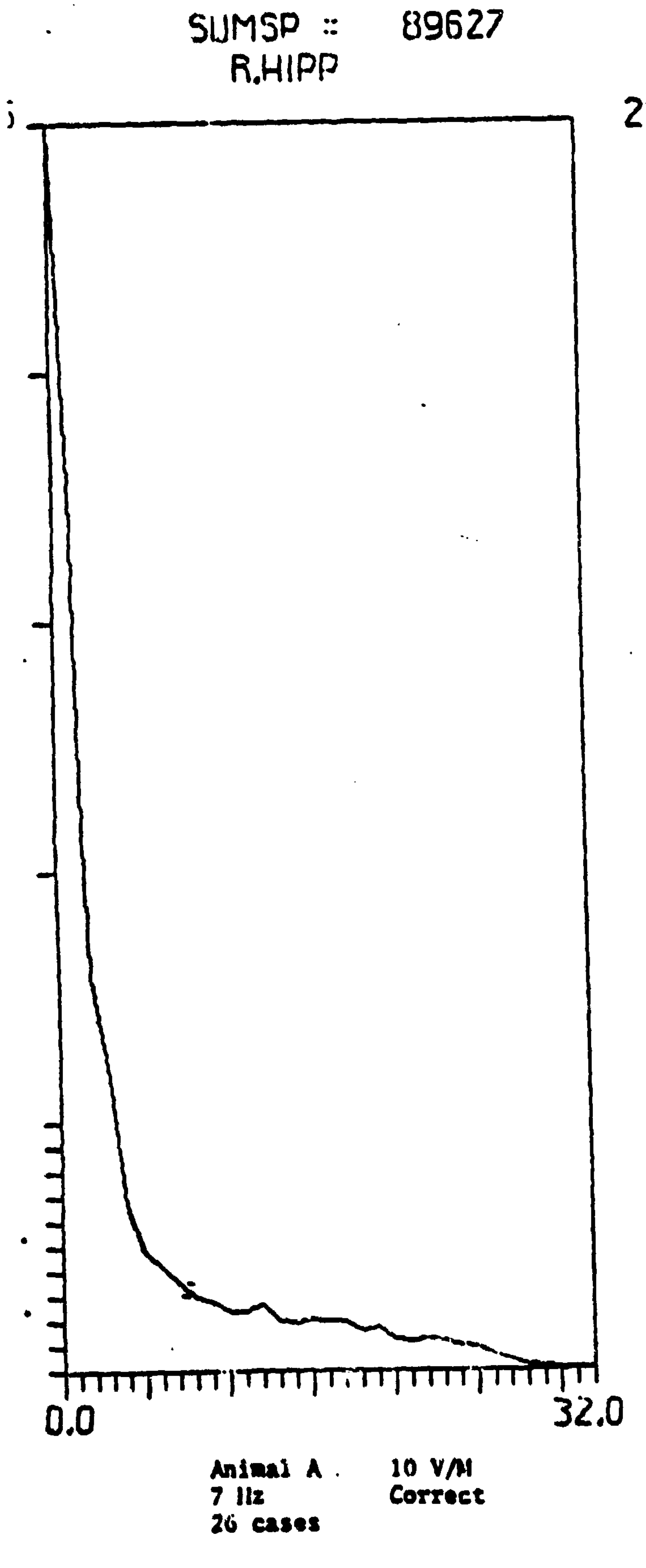
MSK: Correct, Incorrect 10 V/m Series 54

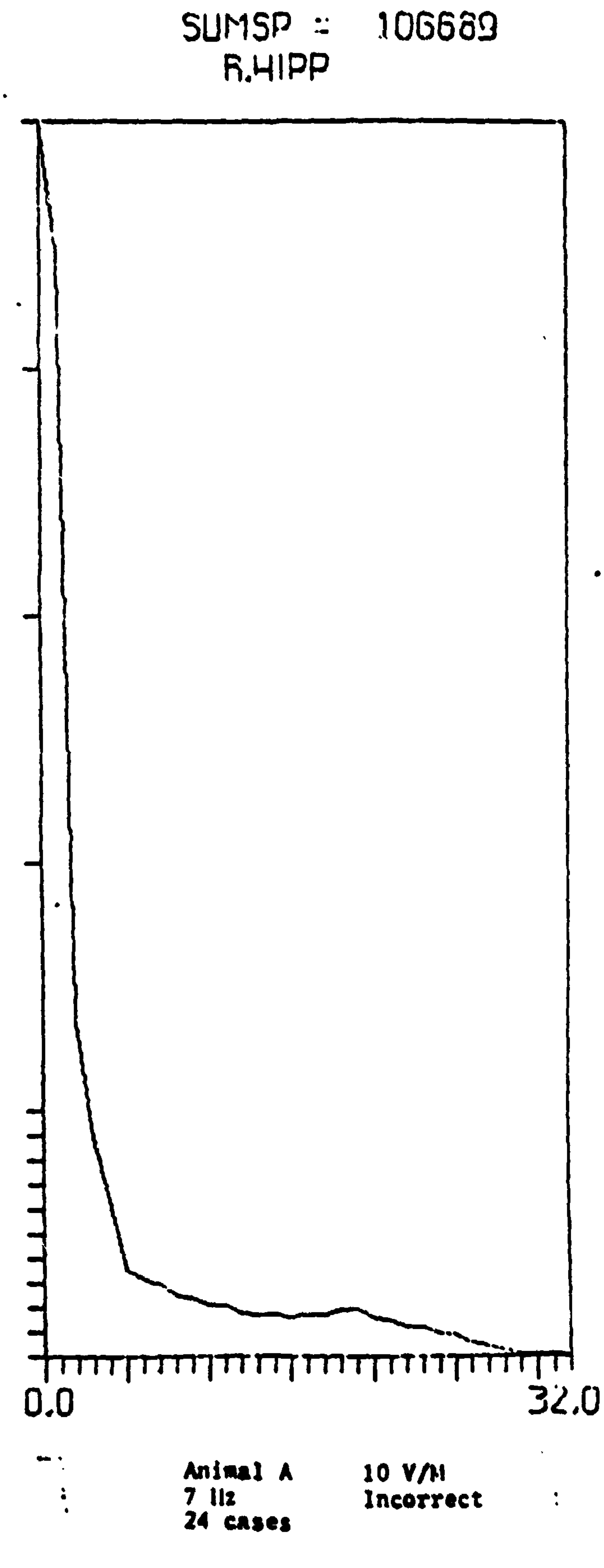
MSK: Correct, Incorrect 56 V/m Series 55

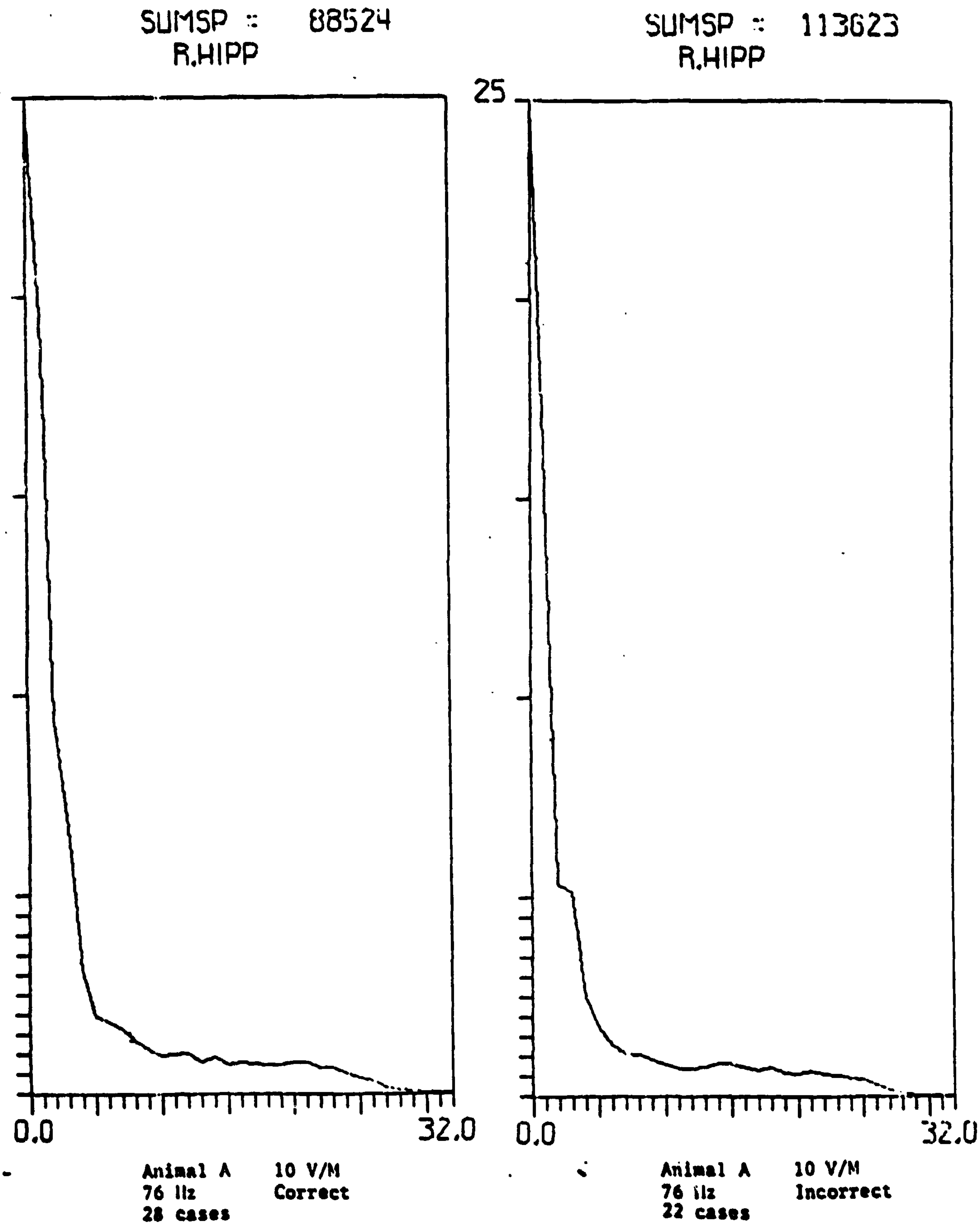
MSK + 60 Hz: Correct, Incorrect 10 V/m Series 56

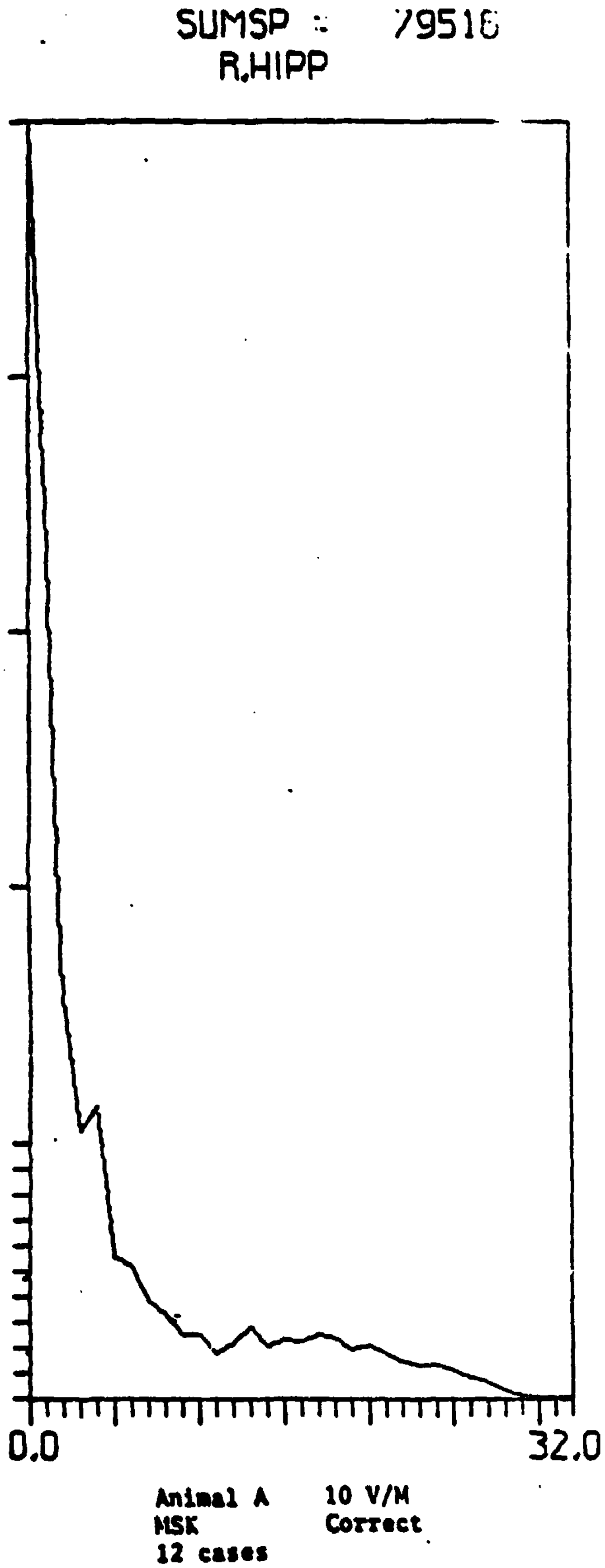
MSK + 60 Hz: Correct, Incorrect 56 V/m Series 57

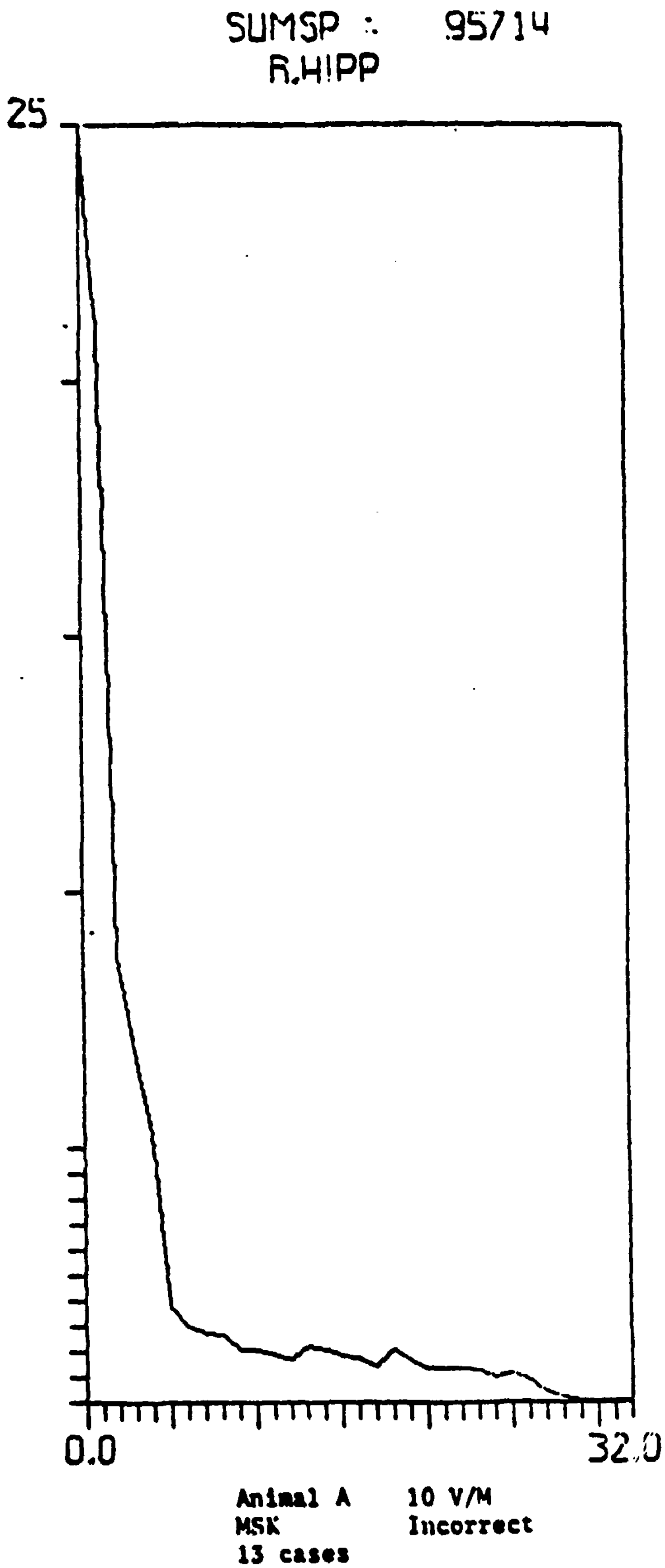

SUMSP = 140519
R.HIPP
5
0.0
32.0
Animal A
Control
49 cases
10 V/M
Correct
SUMSP = 96494
R.HIPP
25
0.0
32.0
Animal A
Control
38 cases
10 V/M
Incorrect

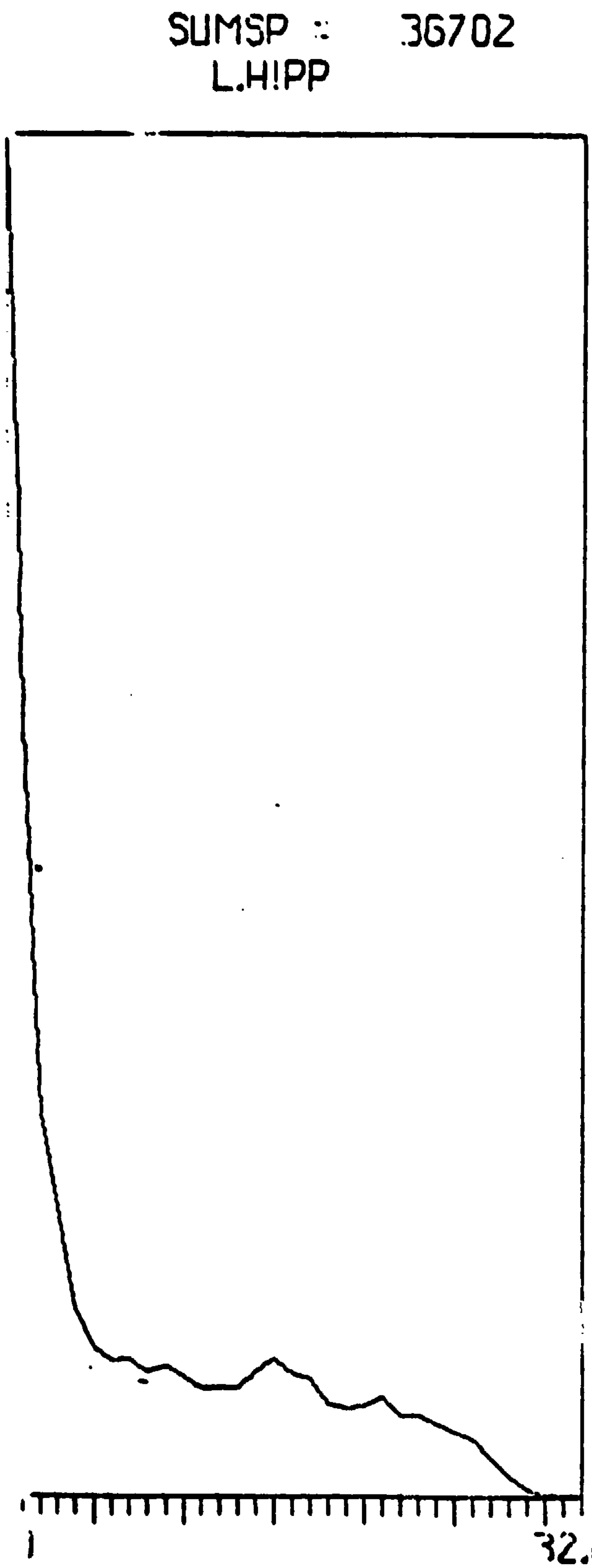

SUMSP = 89627
R.HIPP
0.0
32.0
Animal A
10 V/M
7 Hz
Correct
26 cases


SUMSP = 106689
R.HIPP
0.0
32.0
Animal A
10 V/M
7 Hz
Incorrect
24 cases

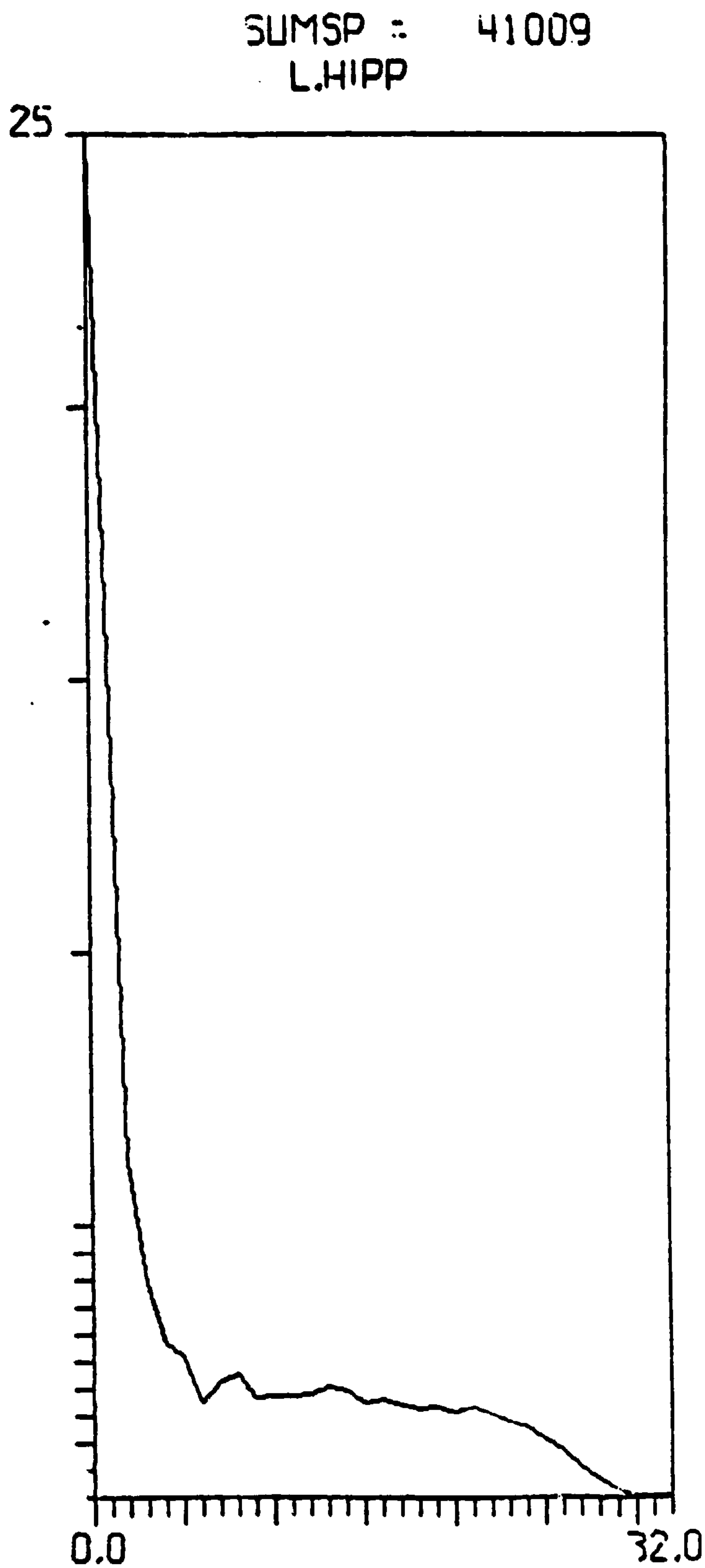

SUMSP = 88524
R.HIPP
SUMSP = 113623
R.HIPP
25
0.0
32.0
0.0
32.0
Animal A 10 V/M
76 Hz Correct
28 cases
Animal A 10 V/M
76 Hz Incorrect
22 cases


SUMSP : 79516
R.HIPP
0.0
32.0
Animal A 10 V/M
MSK Correct
12 cases

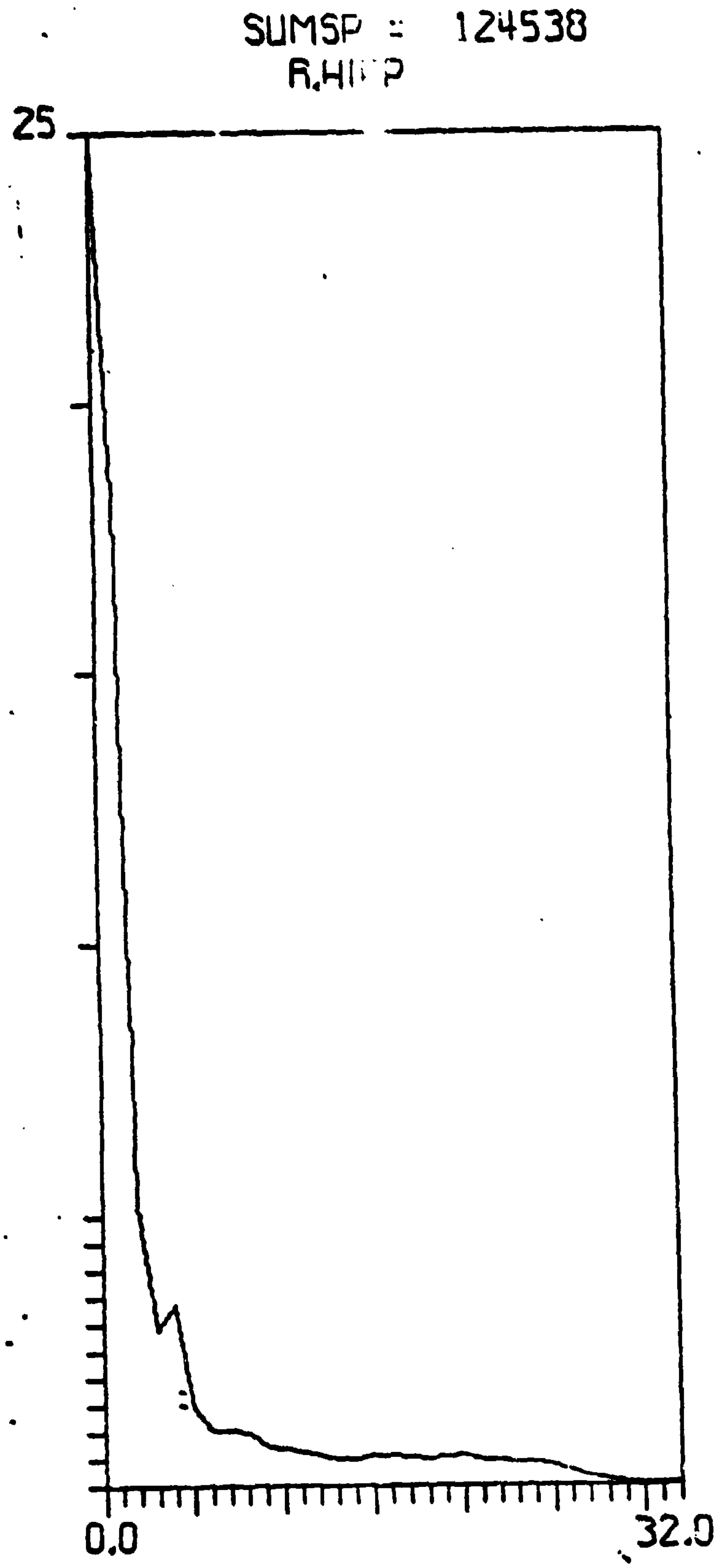

SUMSP : 95714
R.HIPP
25
0.0
32.0
Animal A 10 V/M
MSK Incorrect
13 cases



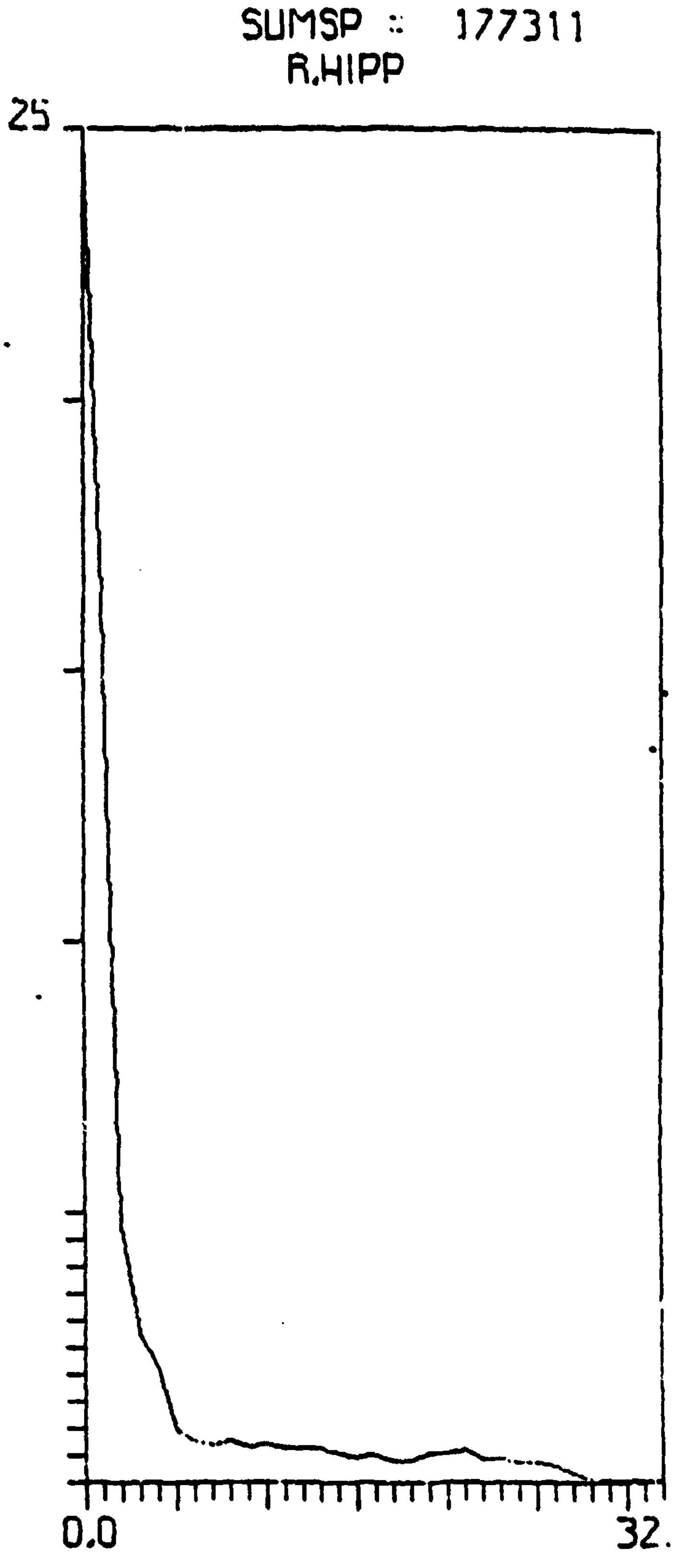
Animal A 10 V/M
Control Correct
49 cases



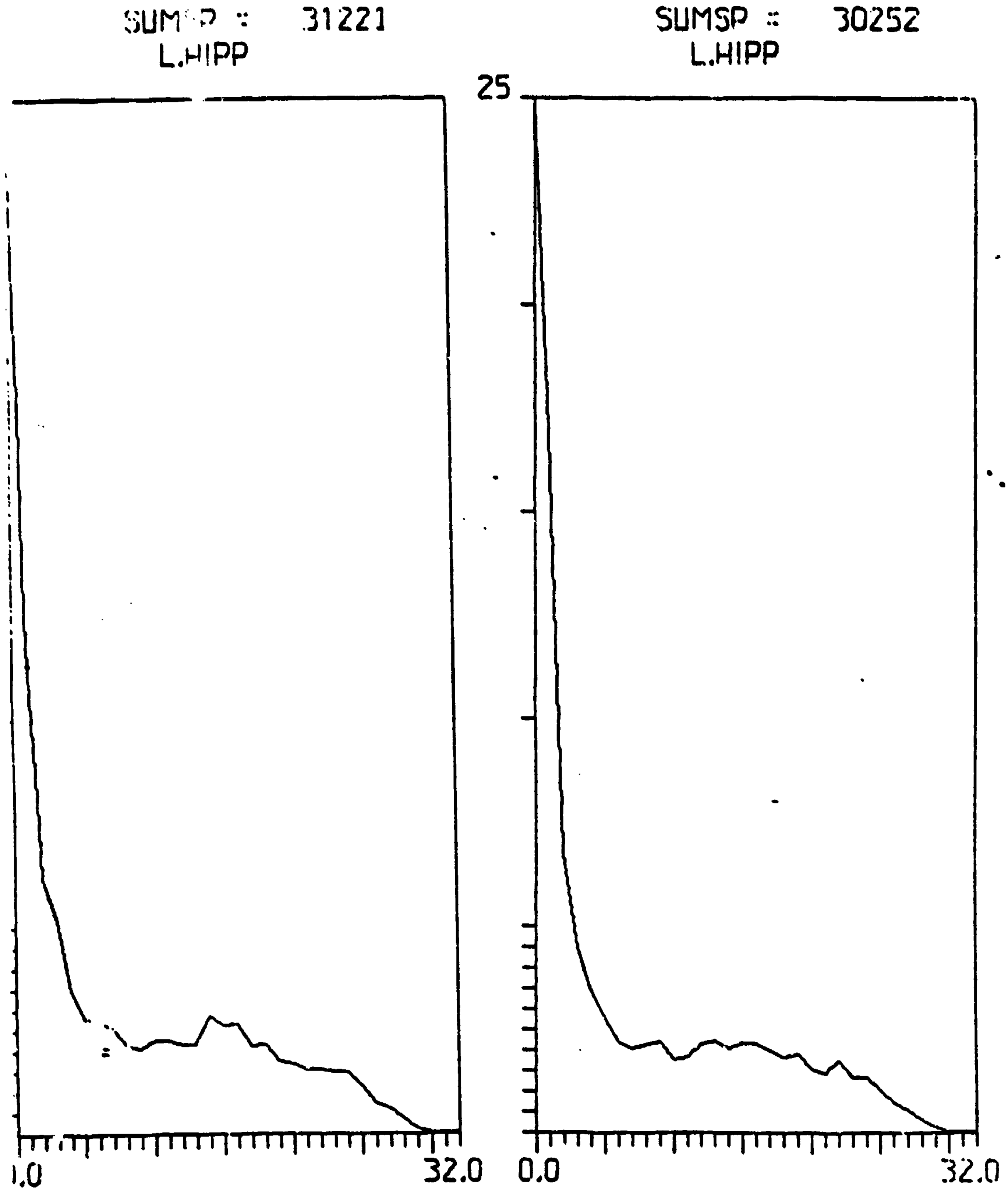
Animal A 10 V/M
Control Incorrect
38 cases



Animal A 10 V/M
MSK+60 Hz Correct
28 cases

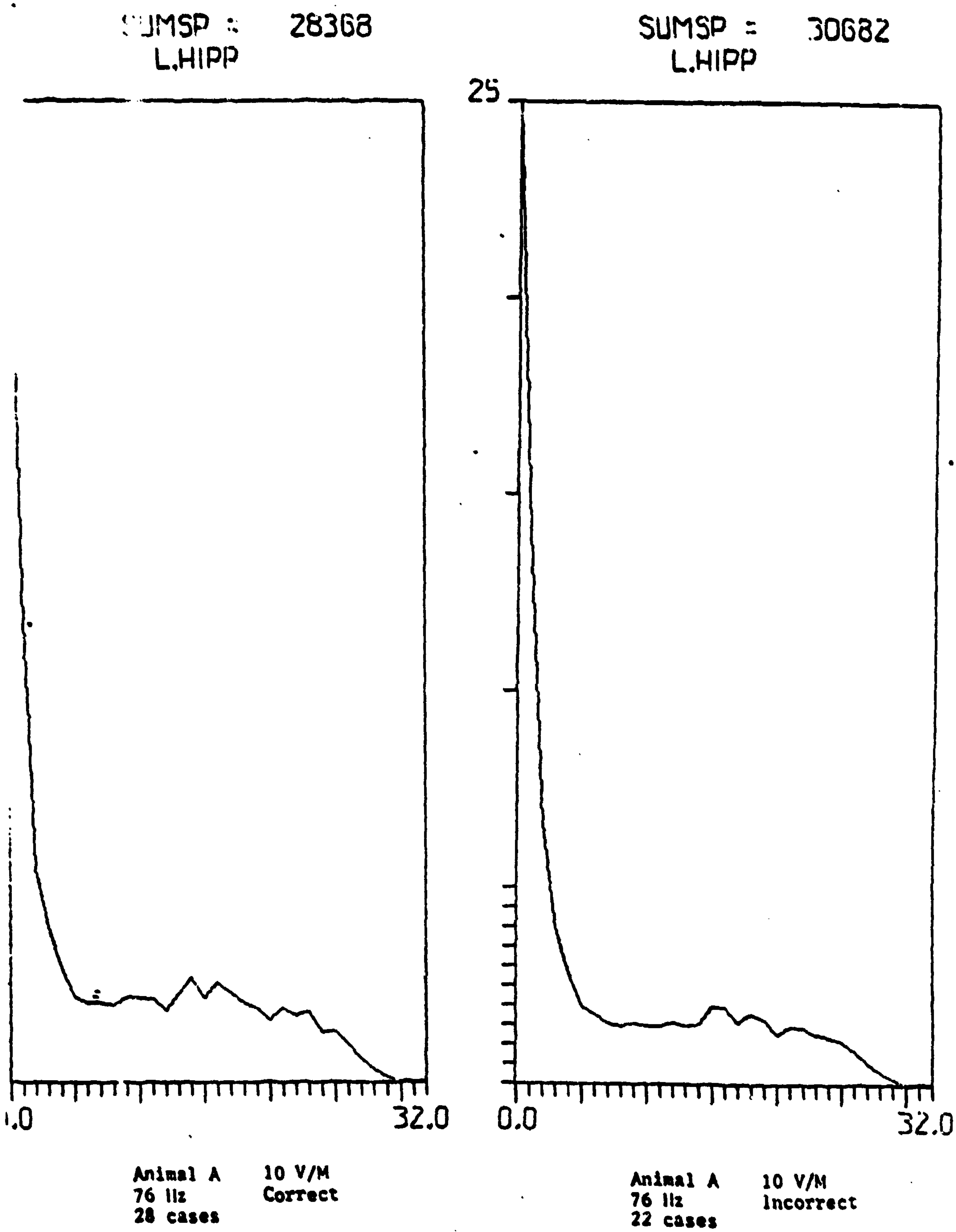


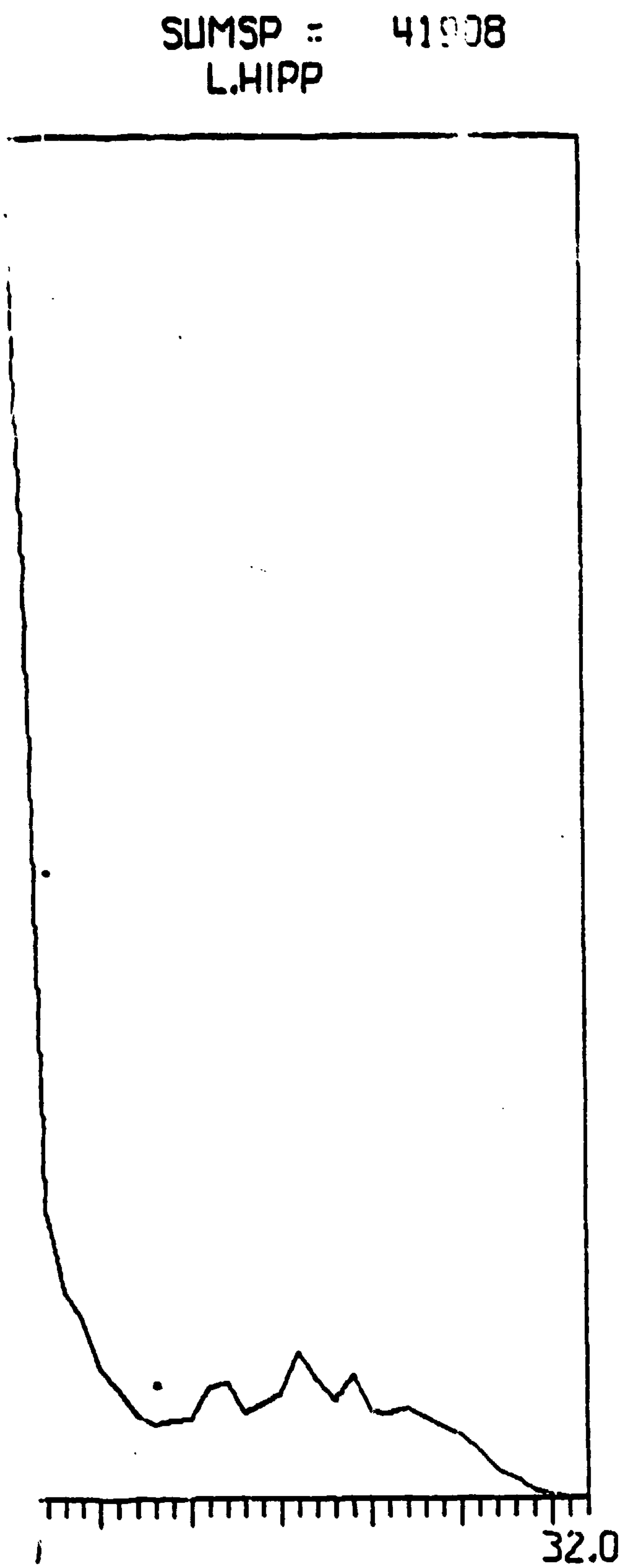
Animal A 10 V/M
MSK+60 Hz Incorrect
21 cases



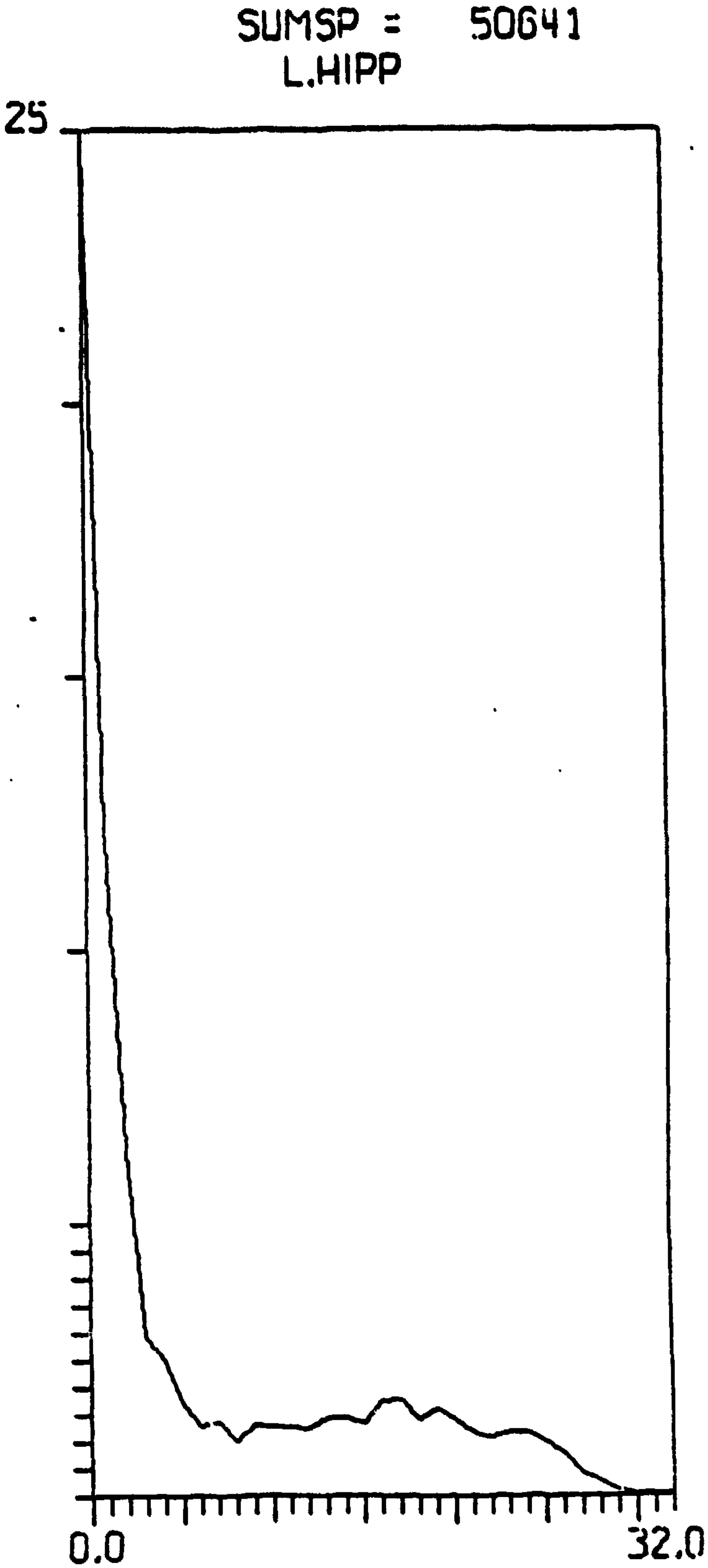
Animal A 10 V/M
7 Hz Correct
26 cases

Animal A 10 V/M
7 Hz Incorrect
24 cases

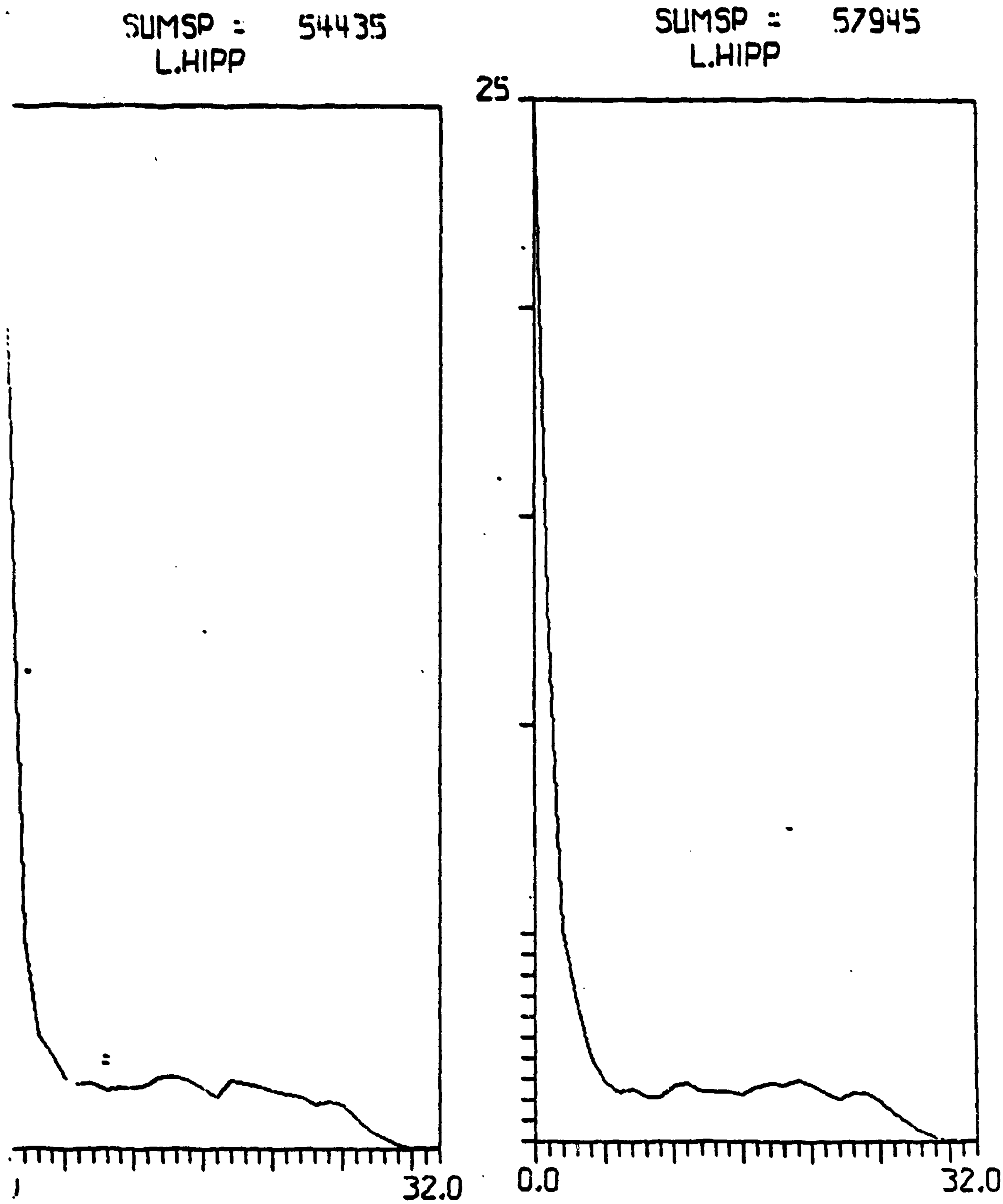

SUMSP = 28368
L.HIPP
0.0
32.0
Animal A
76 Hz
28 cases
10 V/M
Correct
SUMSP = 30682
L.HIPP
25
0.0
32.0
Animal A
76 Hz
22 cases
10 V/M
Incorrect



Animal A **10 V/M**
MSK **Correct**
12 cases

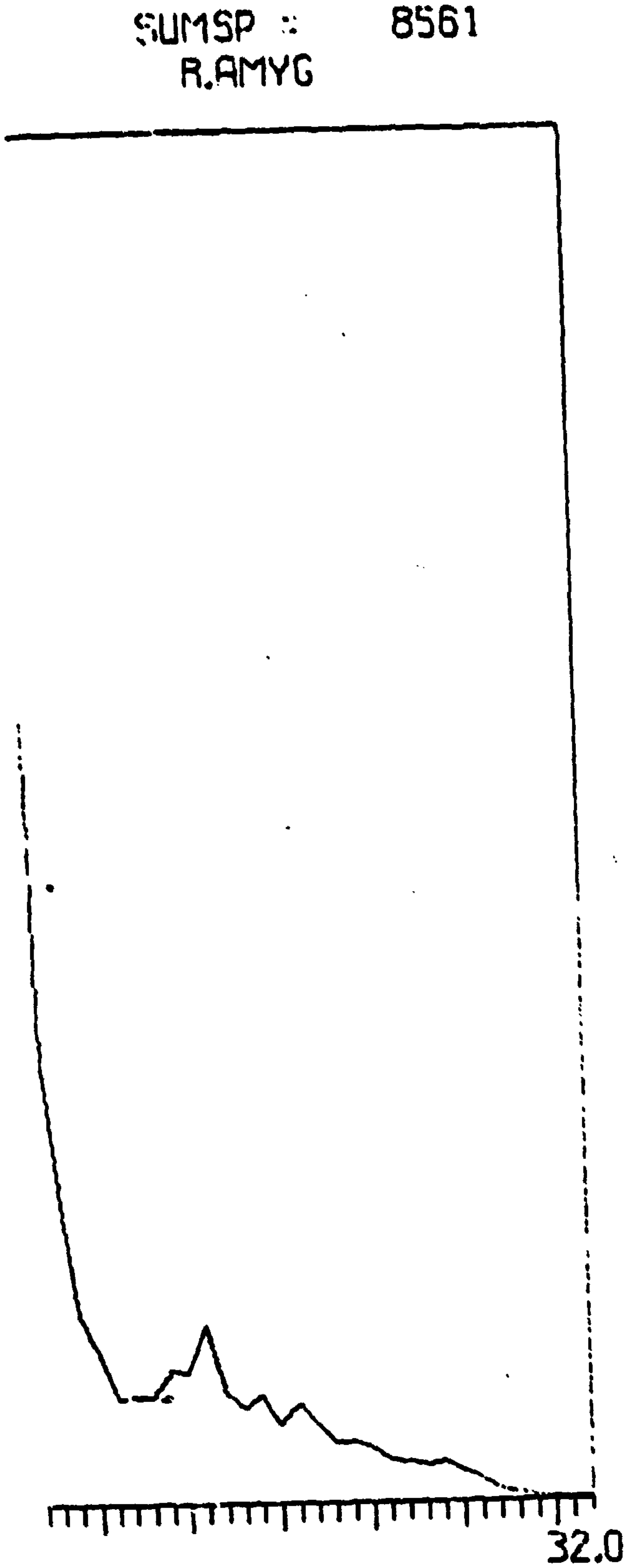


Animal A **10 V/M**
MSK **Incorrect**
13 cases

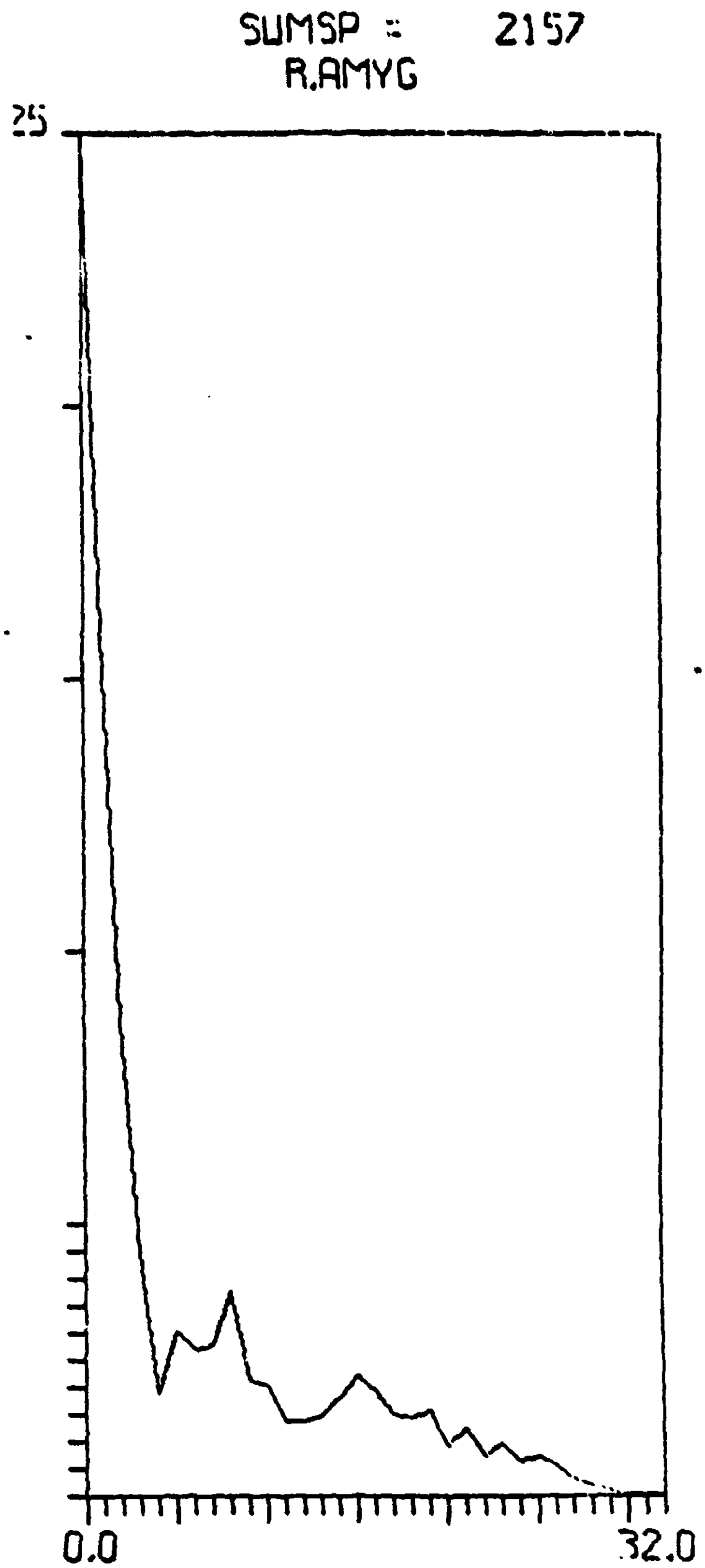


Animal A 10 V/M
MSK+60 Hz Correct
28 cases

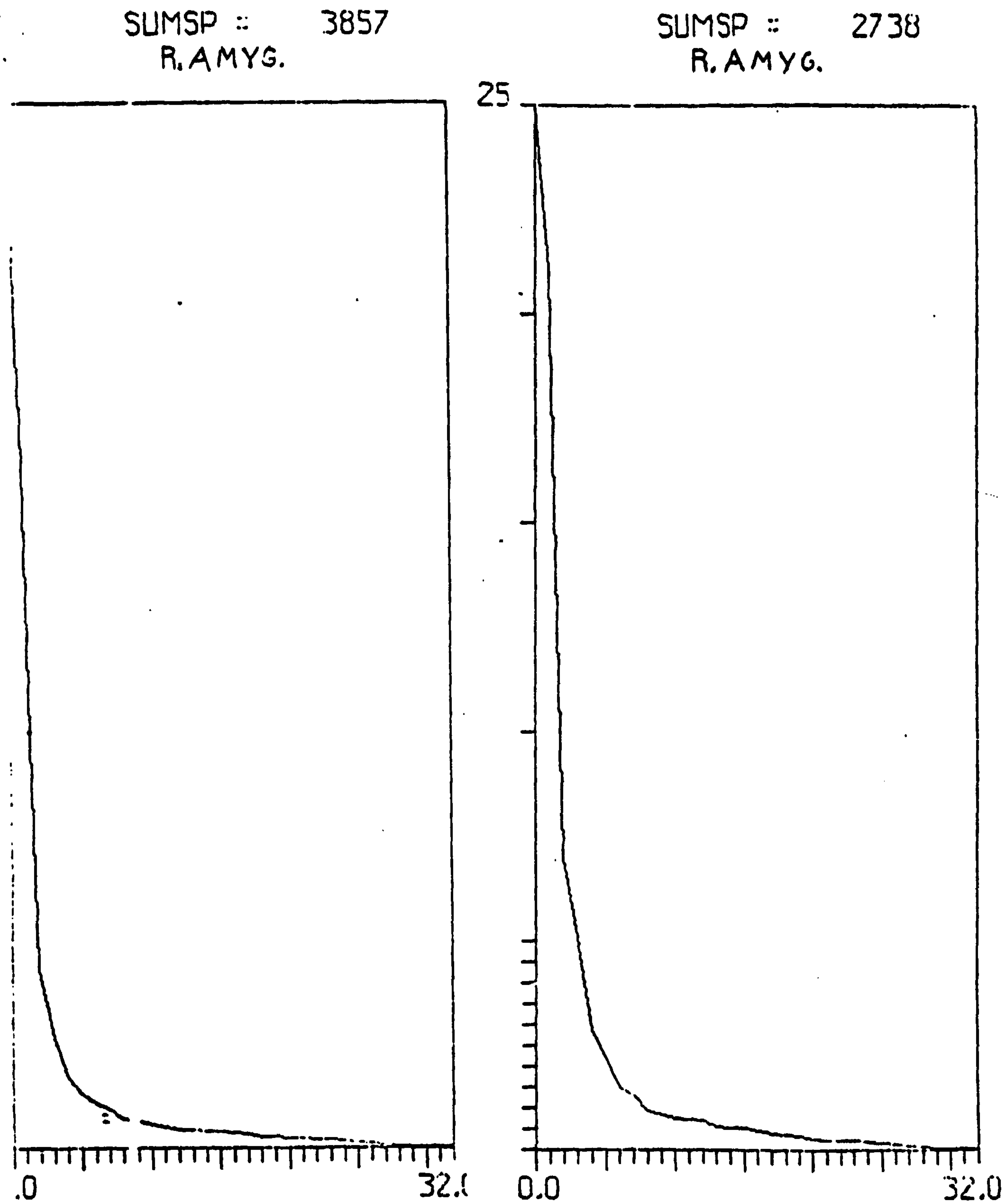
Animal A 10 V/M
MSK+60 Hz Incorrect
21 cases



Animal A 10 V/M
Control Correct
49 cases



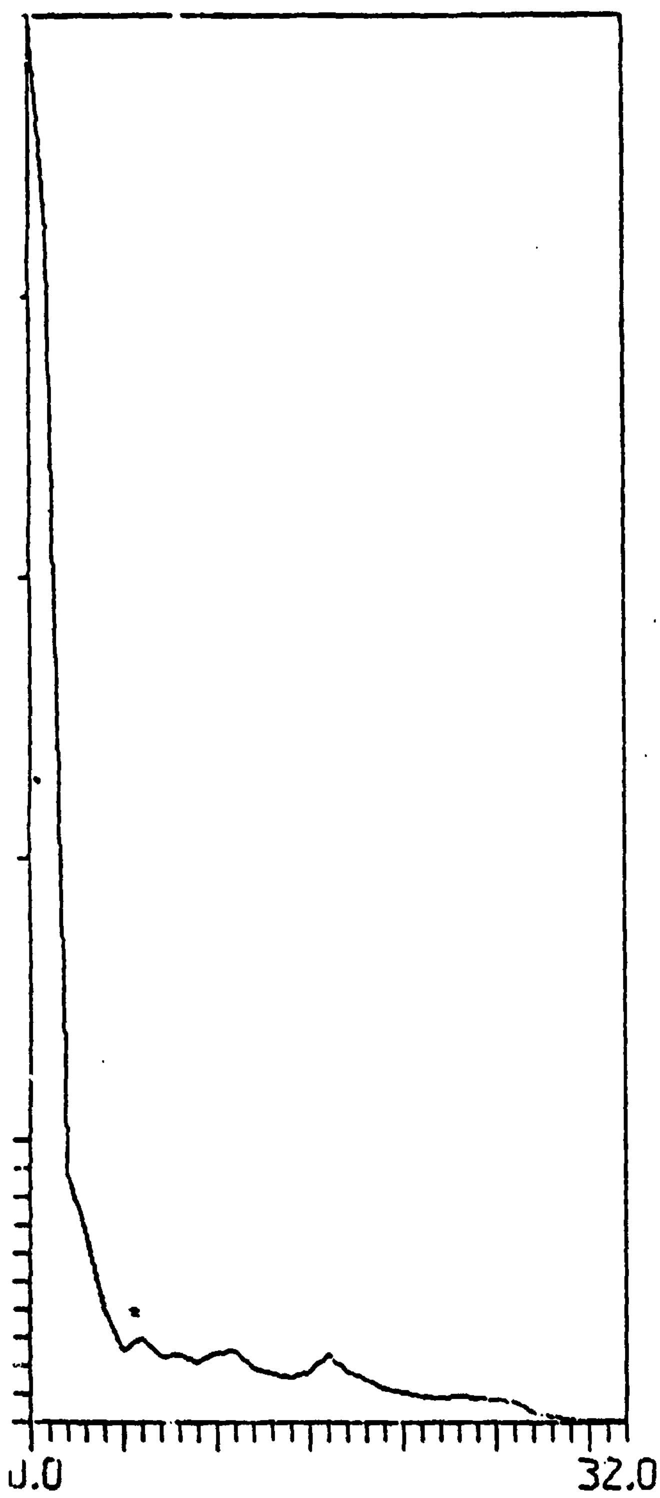
Animal A 10 V/M
Control Incorrect
38 cases



Animal A 56 V/M
Control Correct
50 cases

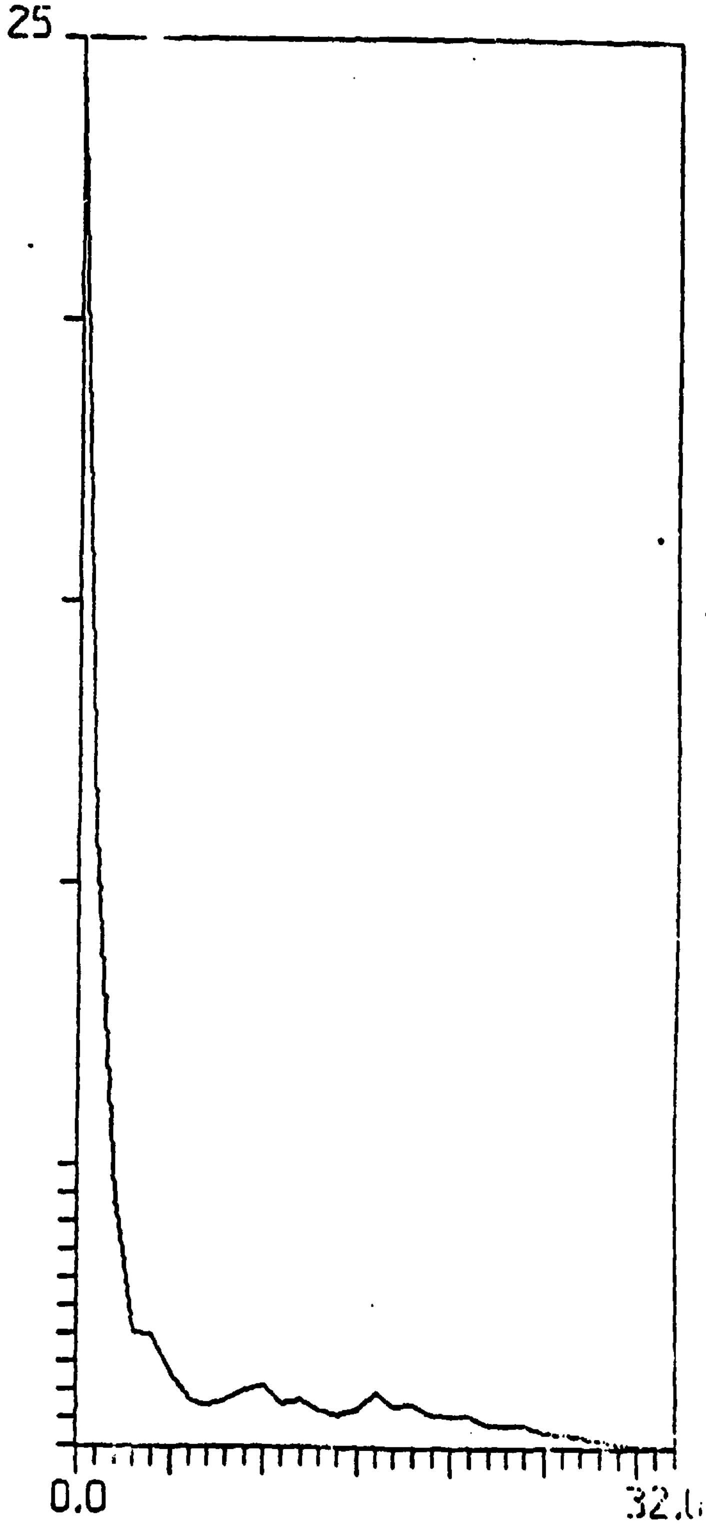
Animal A 56 V/M
Control Incorrect
40 cases

SUMSP :: 24812
R.AMYG

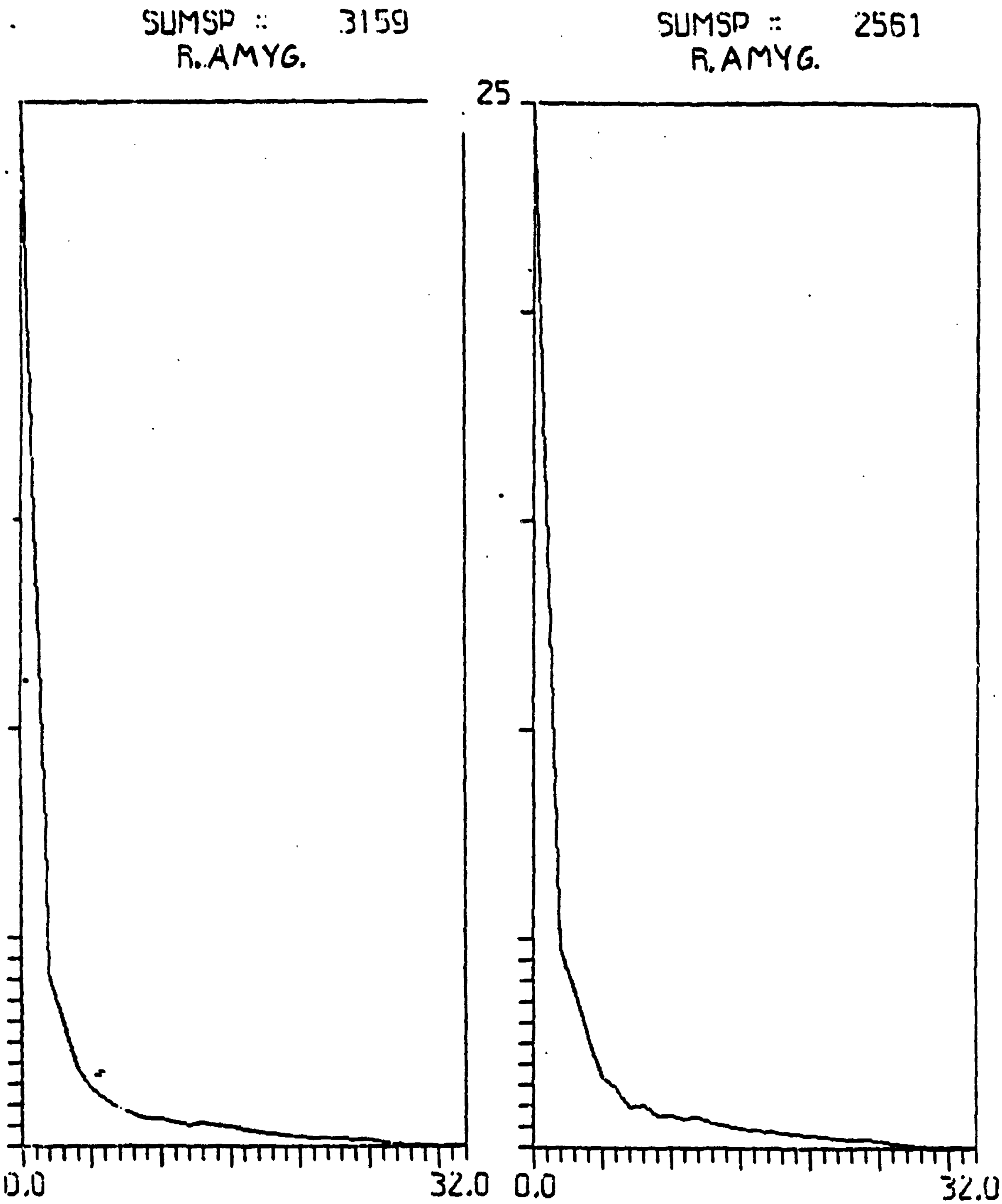


Animal A 7 Hz 26 cases
10 V/M Correct

SUMSP :: 21293
R.AMYG

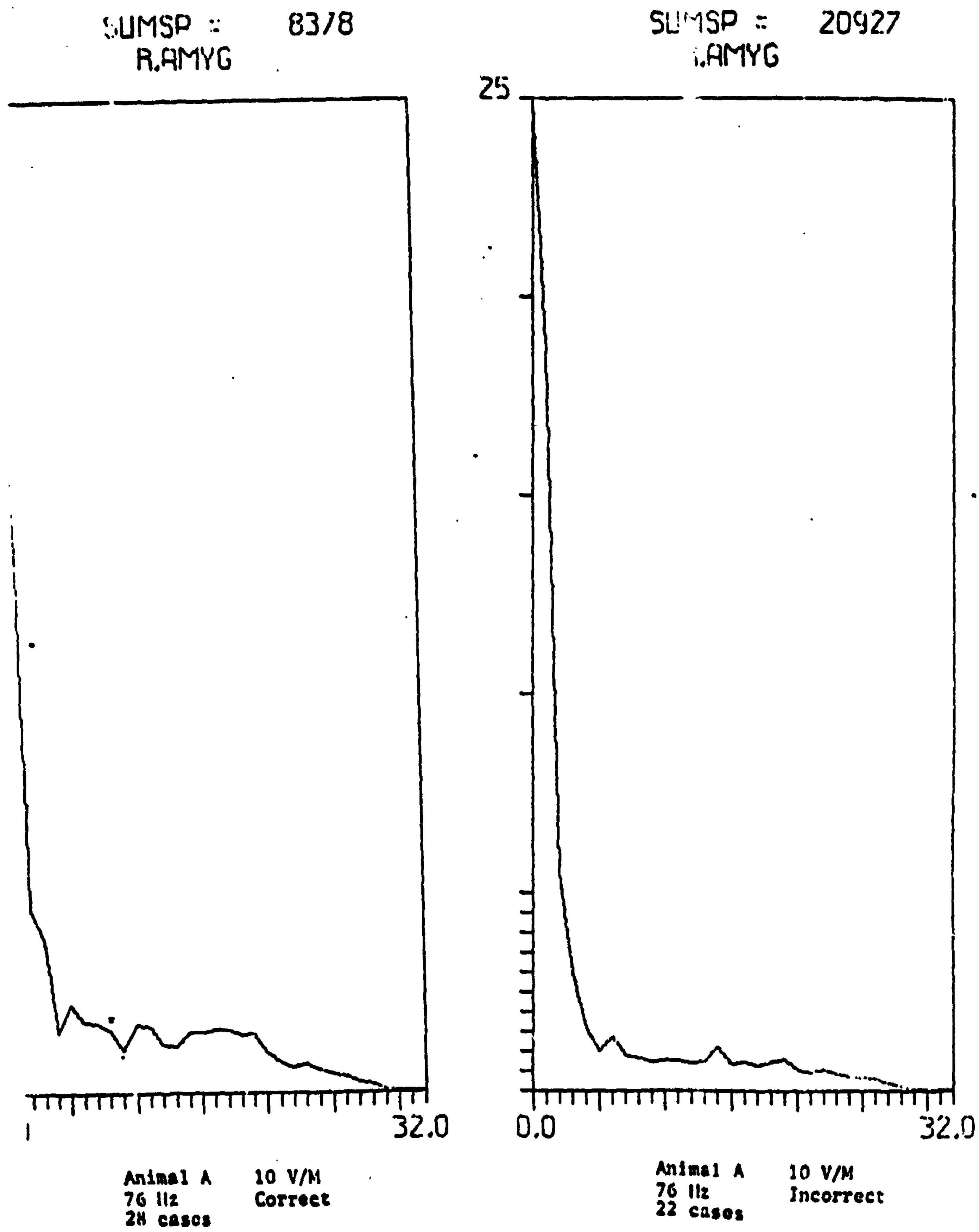


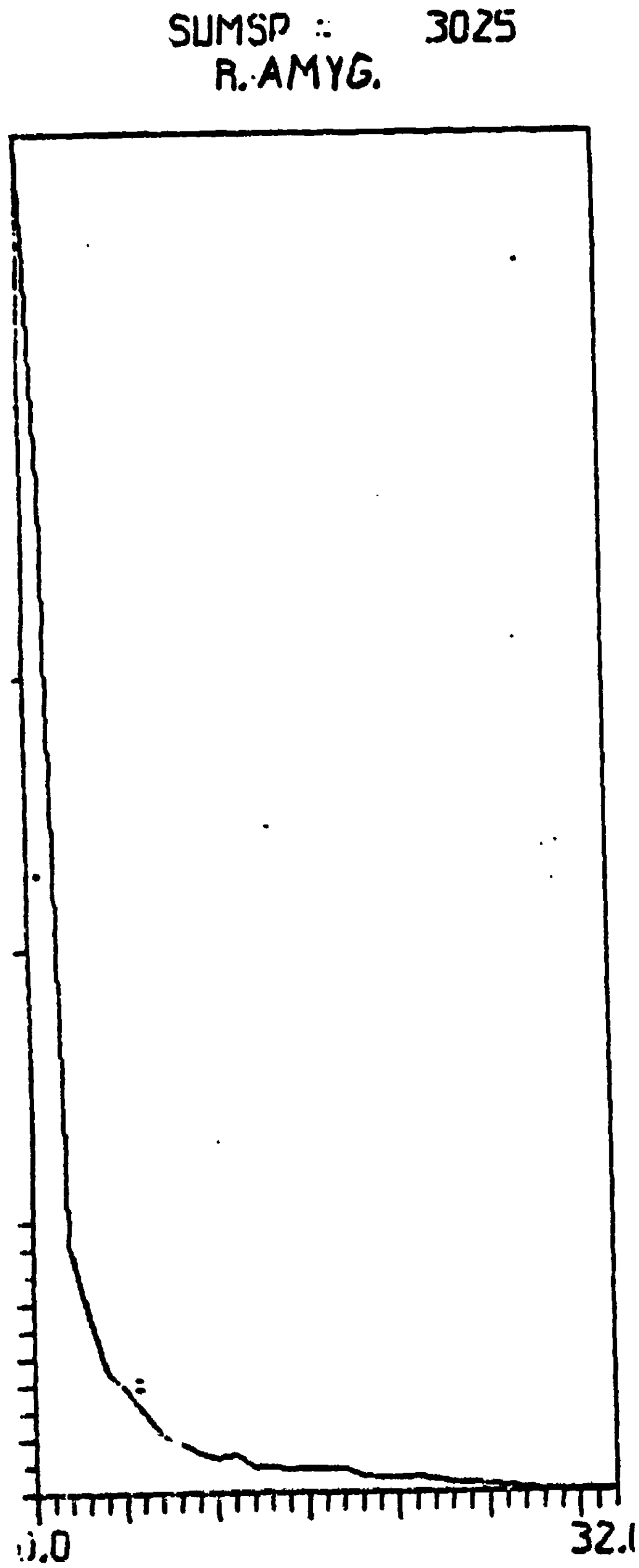
Animal A 7 Hz 24 cases
10 V/M Incorrect



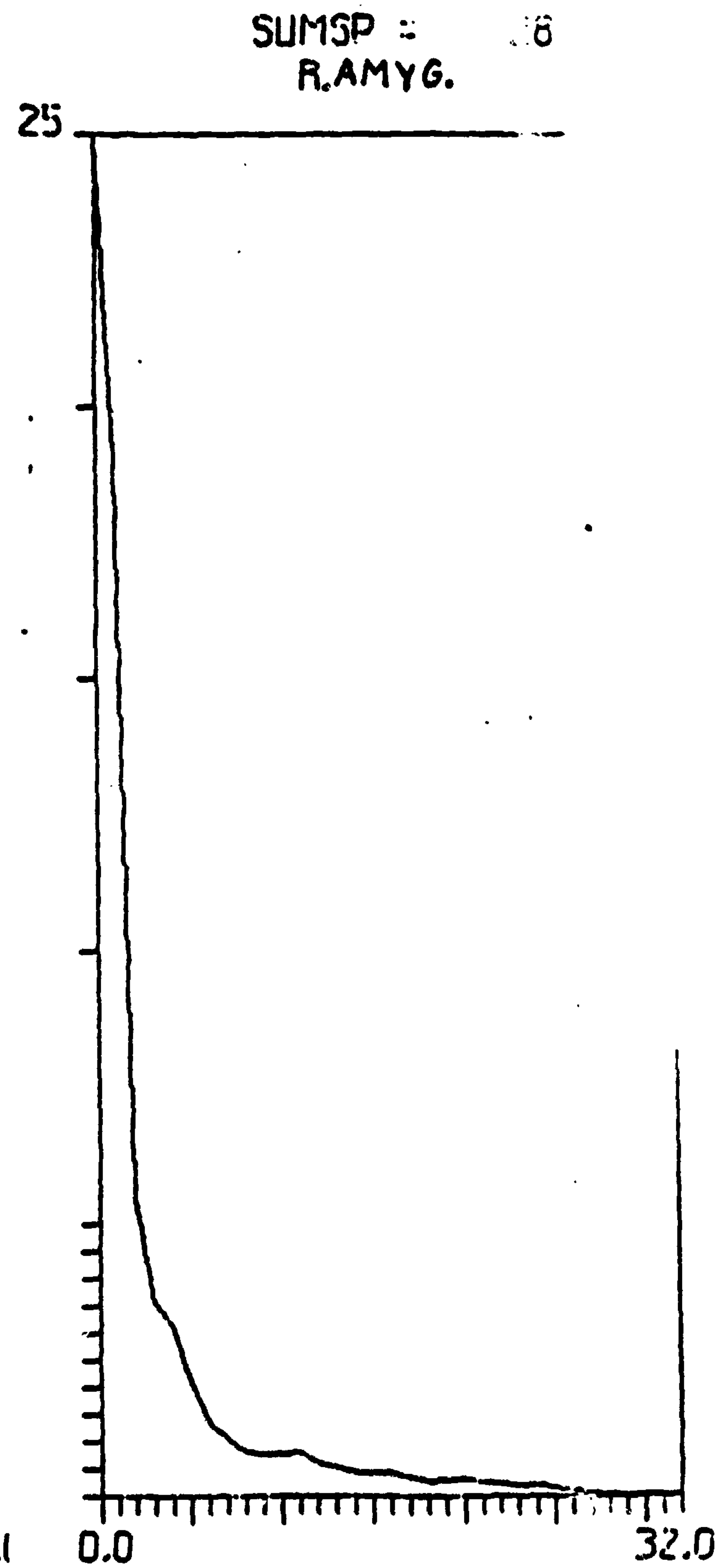
Animal A 56 V/M
7 Hz Correct
24 cases

Animal A 56 V/M
7 Hz Incorrect
24 cases

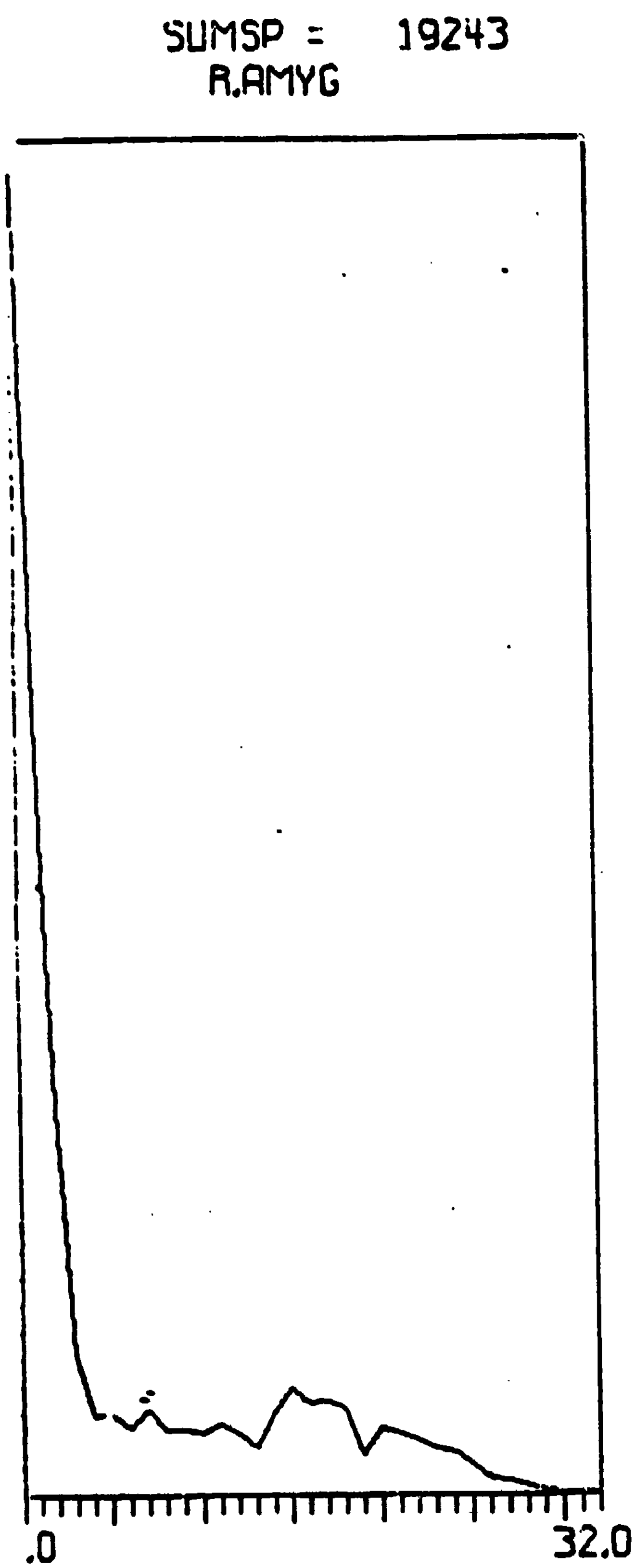

SUMSP = 8378
R.AMYG
Animal A 10 V/M
76 Hz Correct
28 cases
32.0
SUMSP = 20927
AMYG
25
0.0
32.0
Animal A 10 V/M
76 Hz Incorrect
22 cases



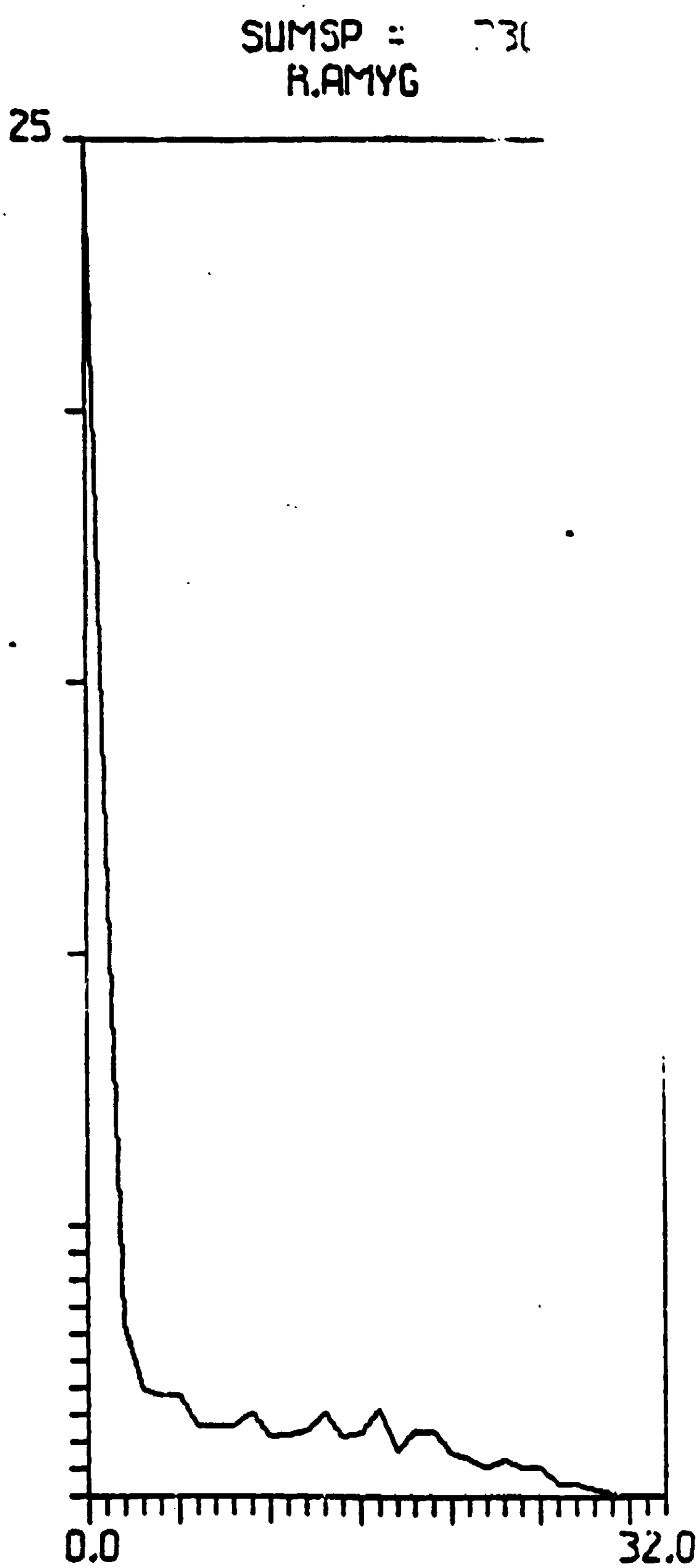
Animal A 56 V/M
76 Hz Correct
17 cases



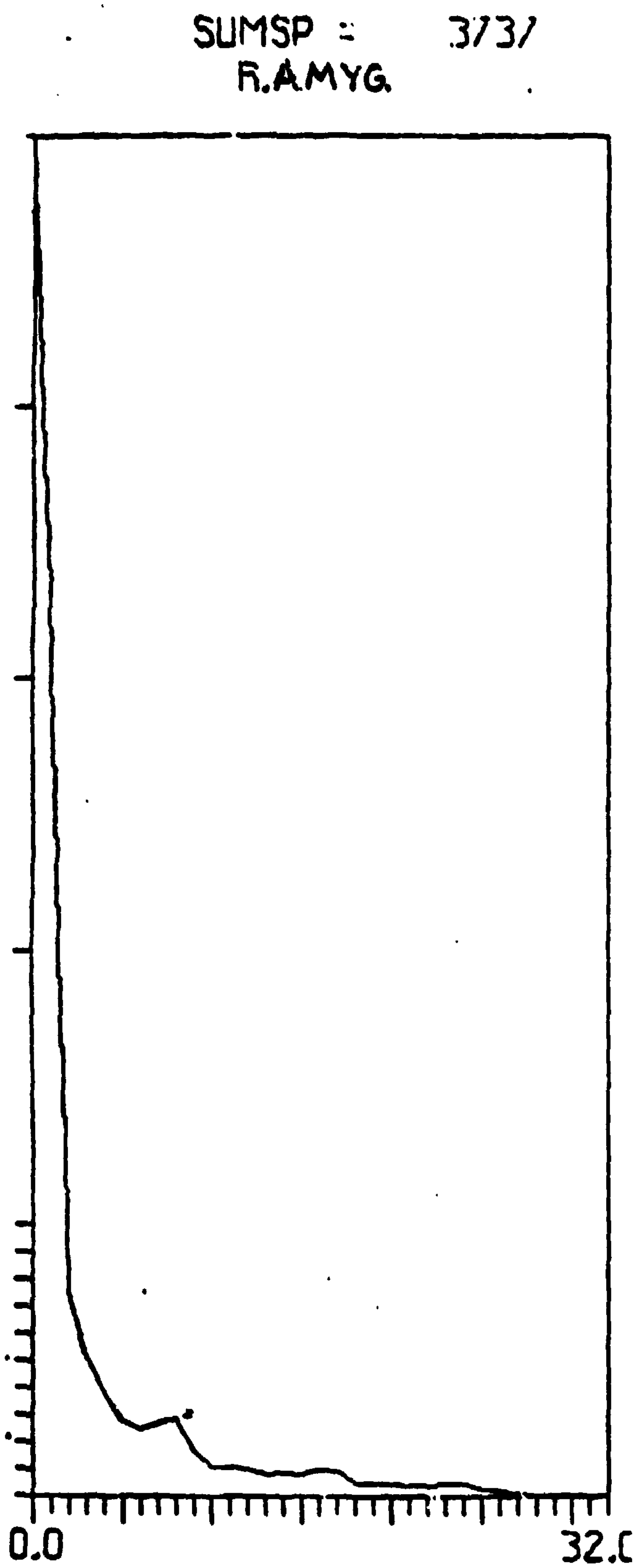
Animal A 56 V/M
76 Hz



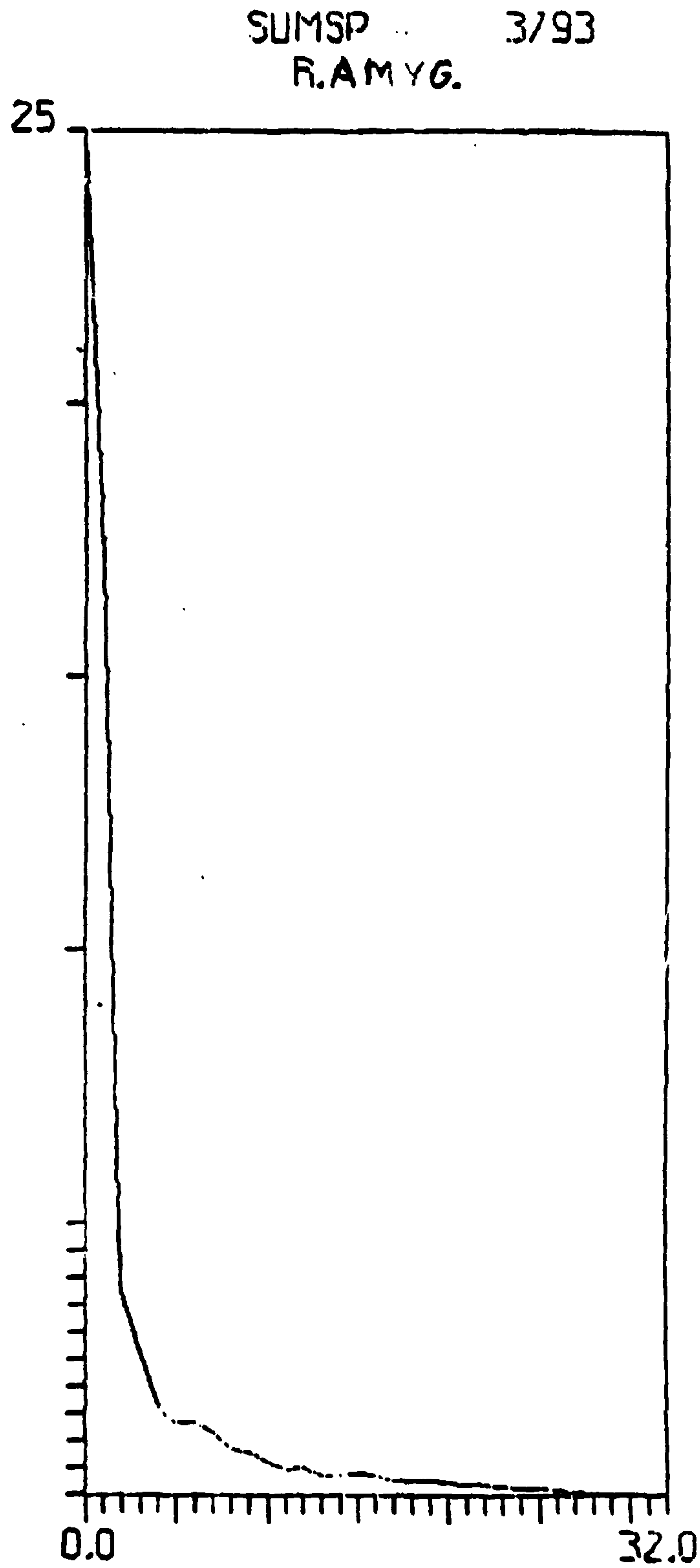
Animal A 10 V/M
MSK Correct
12 cases



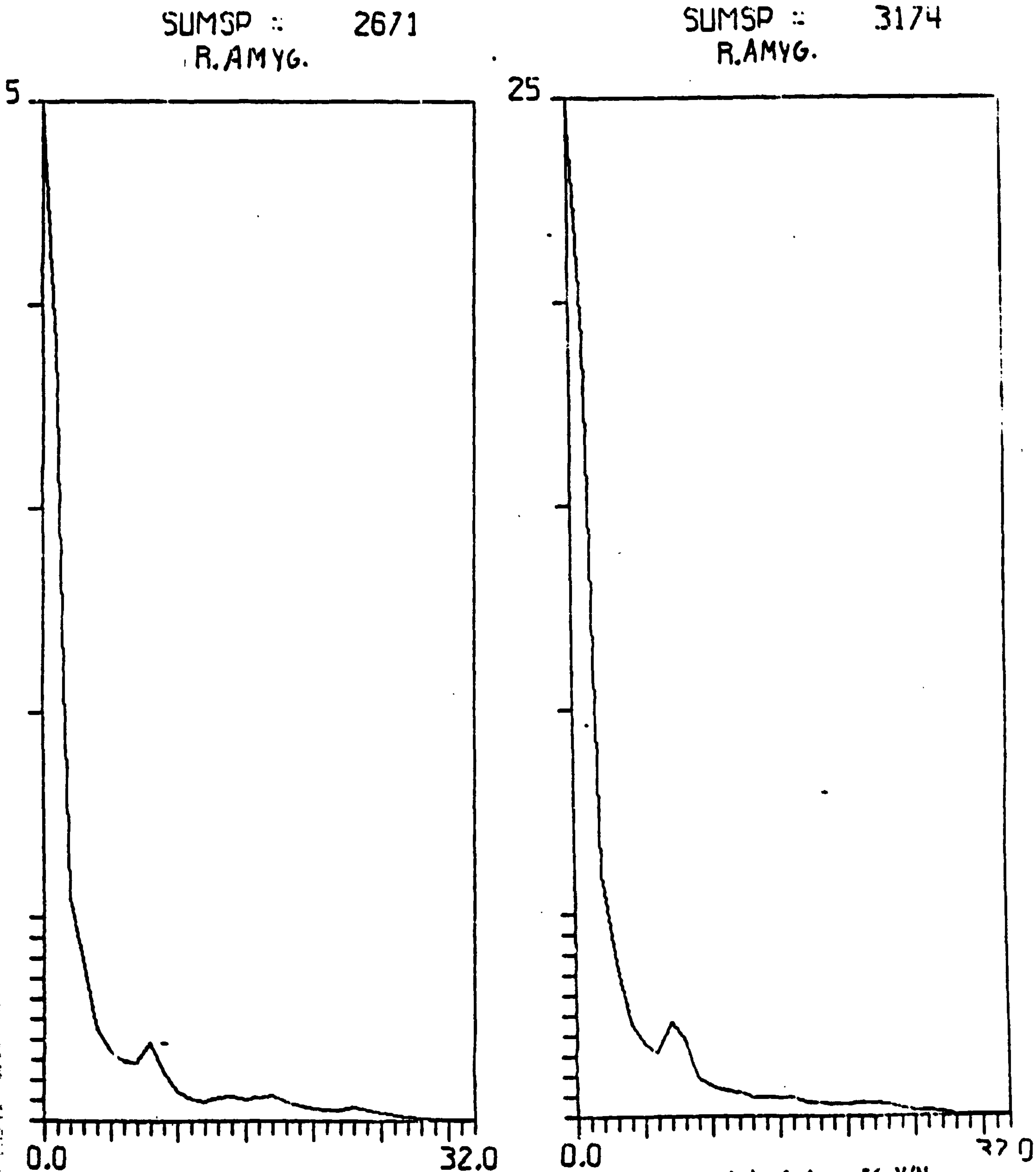
Animal A 10 V/M
MSK



Animal A 56 V/M
MSK Correct
24 cases

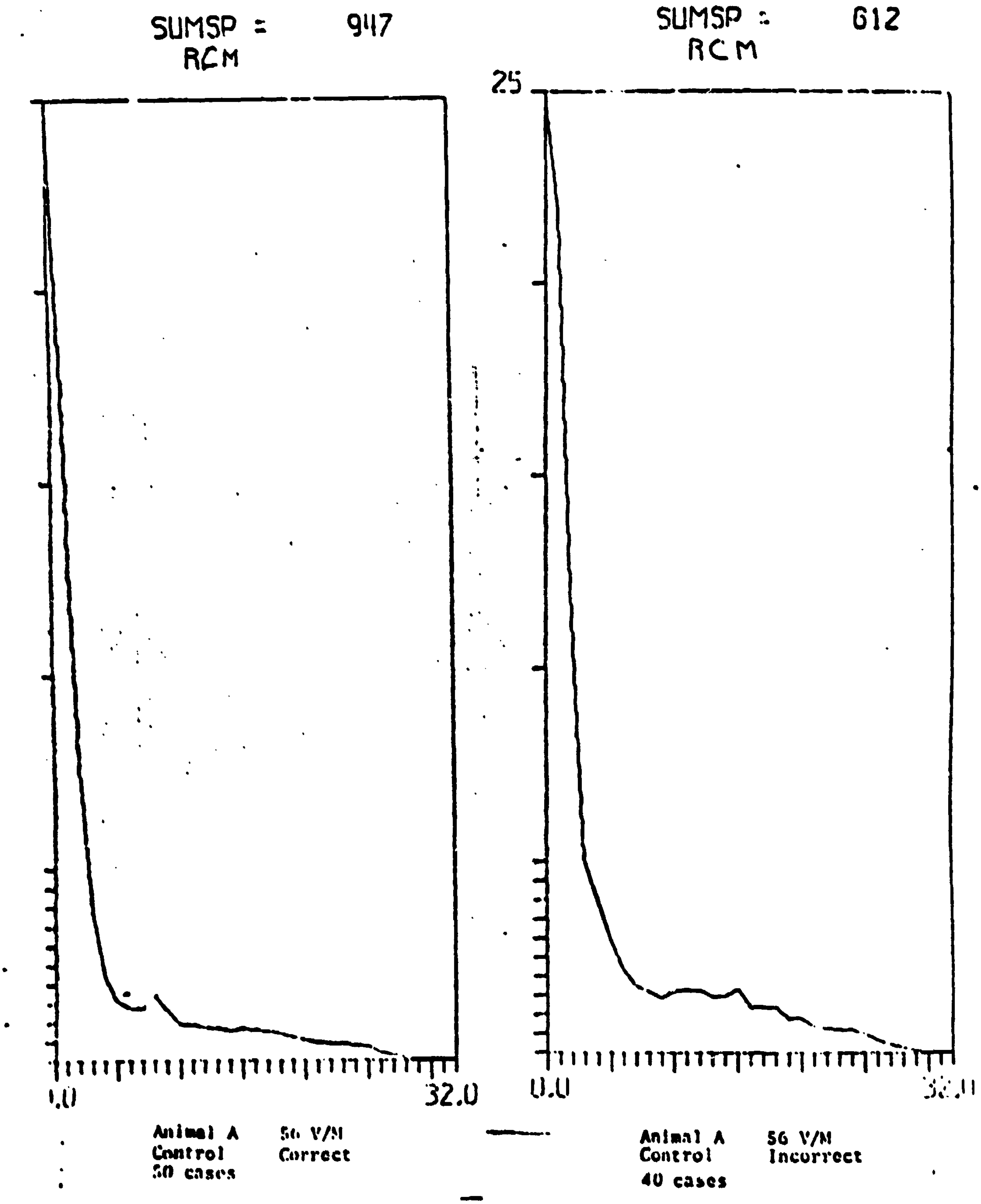


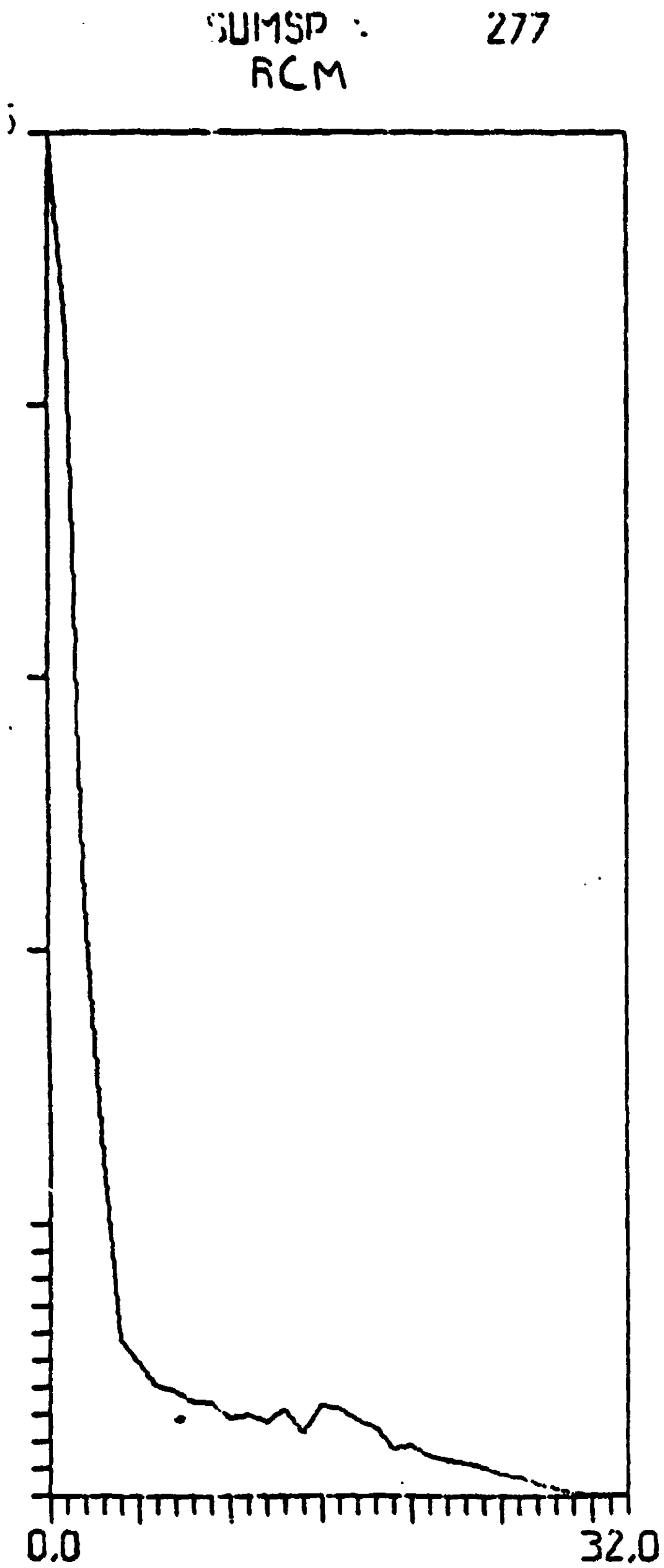
Animal A 56 V/M
MSK Incorrect
15 cases



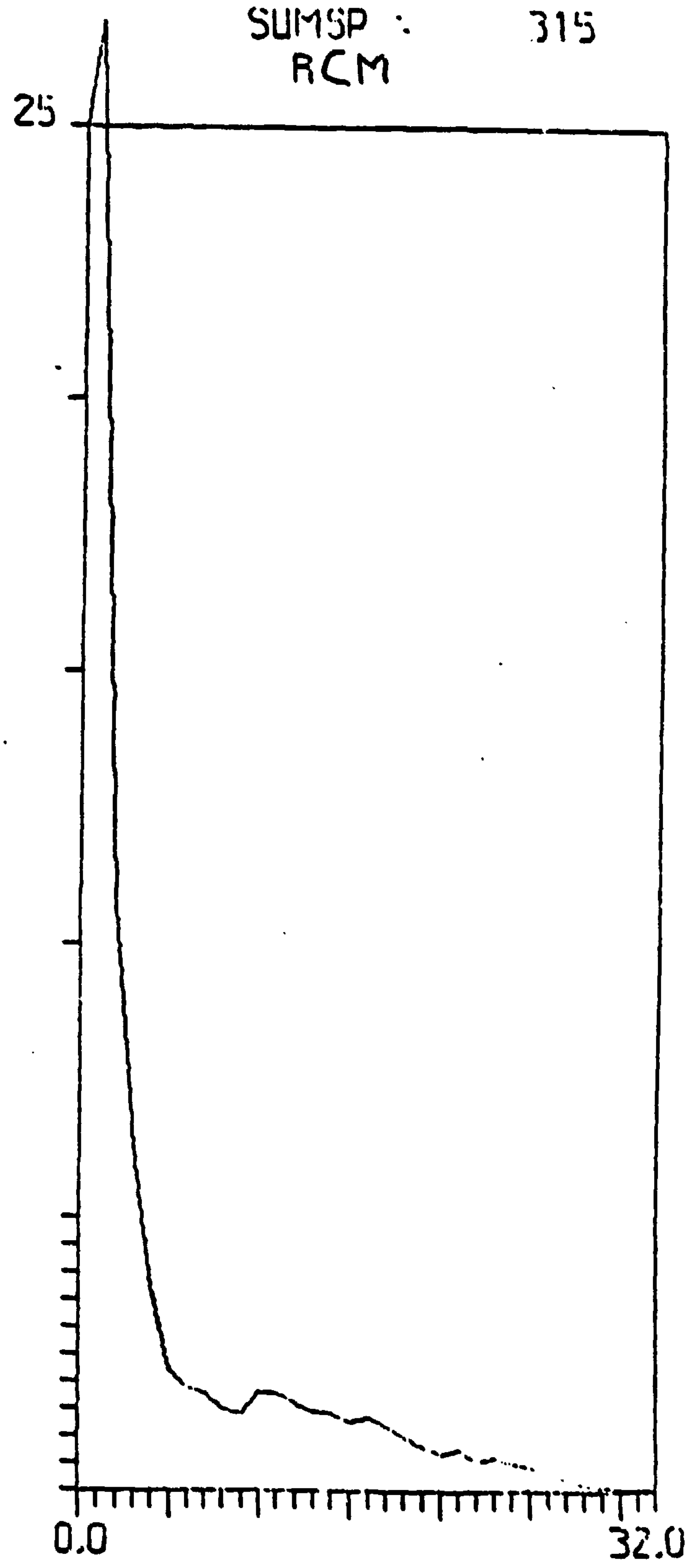
Animal A 56 V/M
NSK+60 Hz Correct
25 cases

Animal A 56 V/M
NSK+60 Hz Incorrect
23 cases


SUMSP = 947
RCM
0.0
32.0
Animal A
Control
50 cases
56 V/M
Correct
SUMSP = 612
RCM
25
0.0
Animal A
Control
40 cases
56 V/M
Incorrect

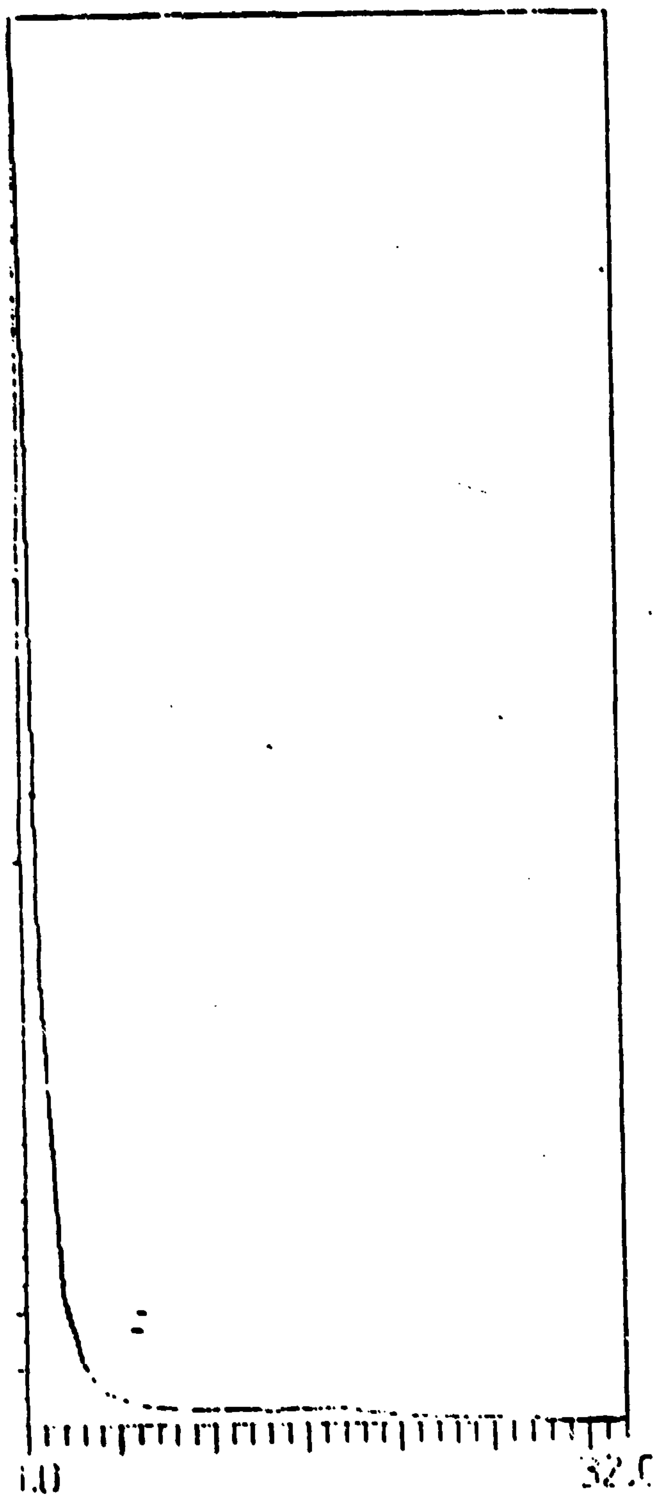


Animal A 56 V/M
7 Hz Correct
24 cases



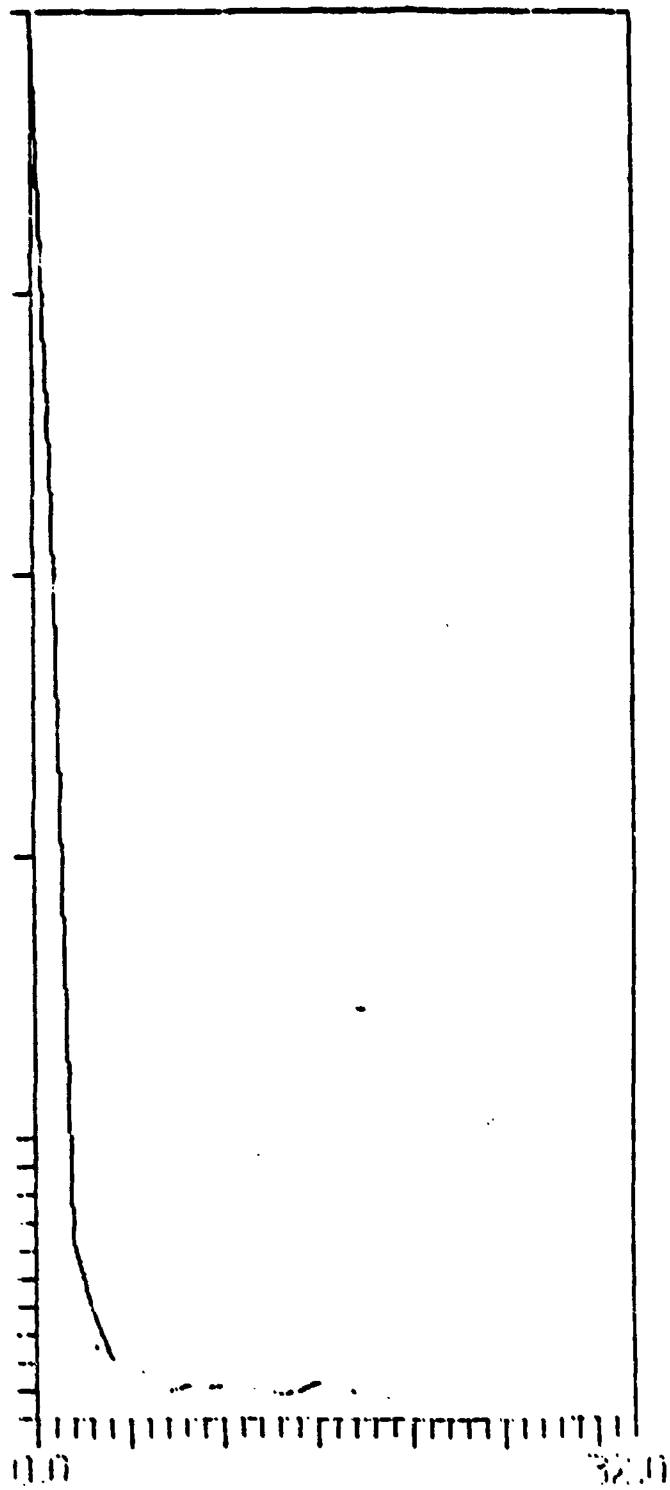
Animal A 56 V/M
7 Hz Incorrect
24 cases

SUMSP : 1050
RCM

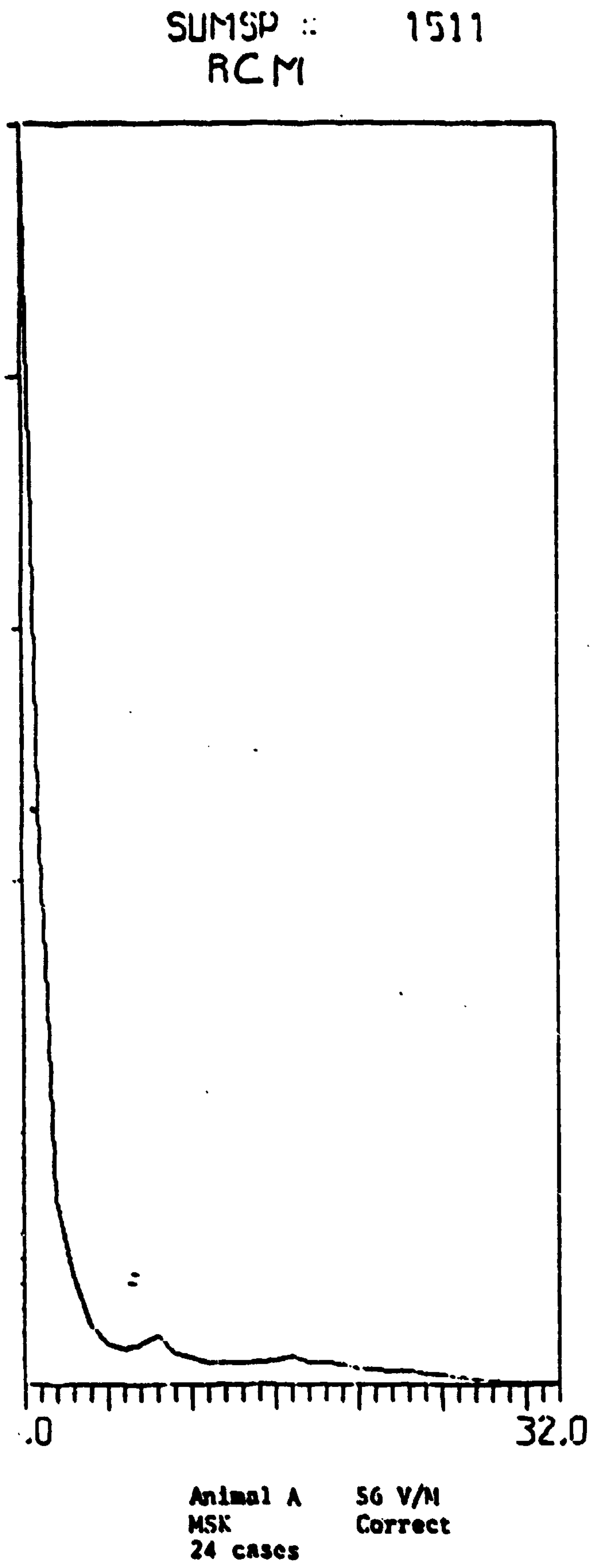


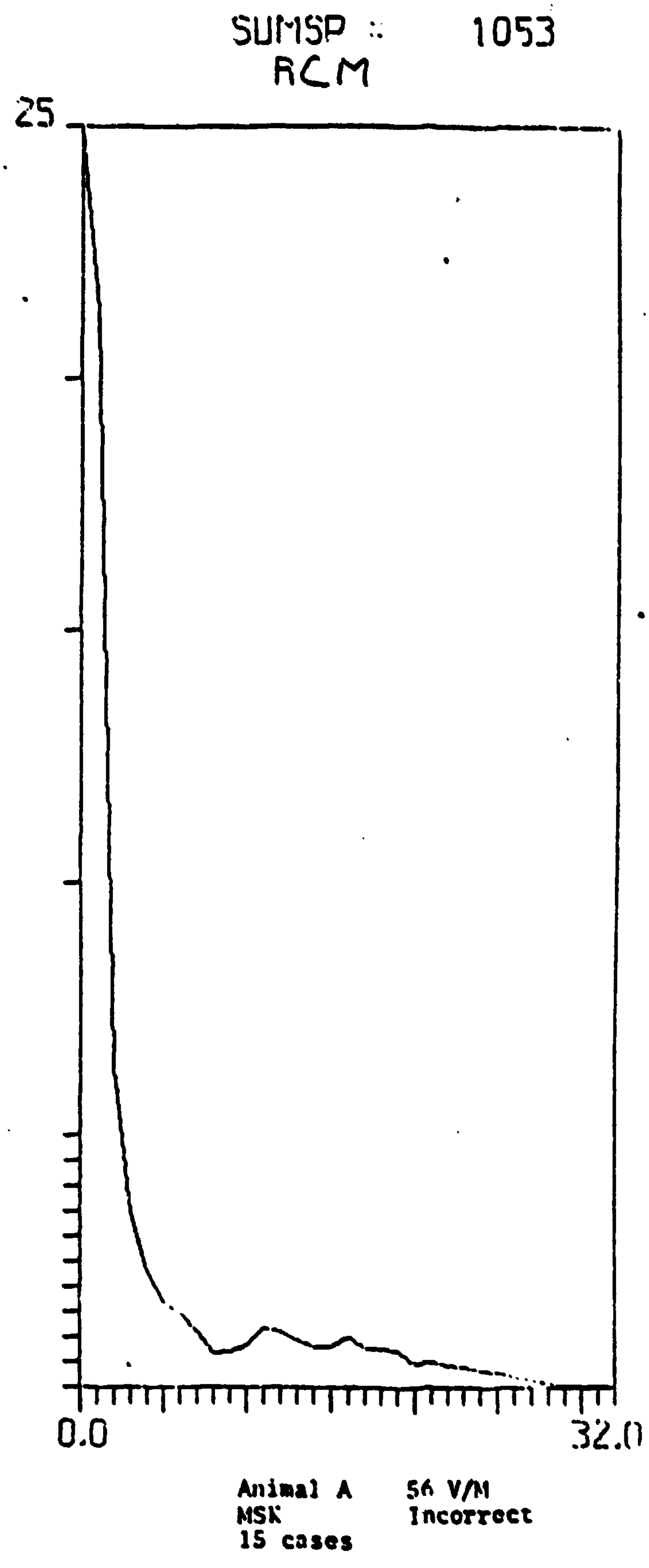
Animal A 76 Hz 17 cases
56 V/M Correct

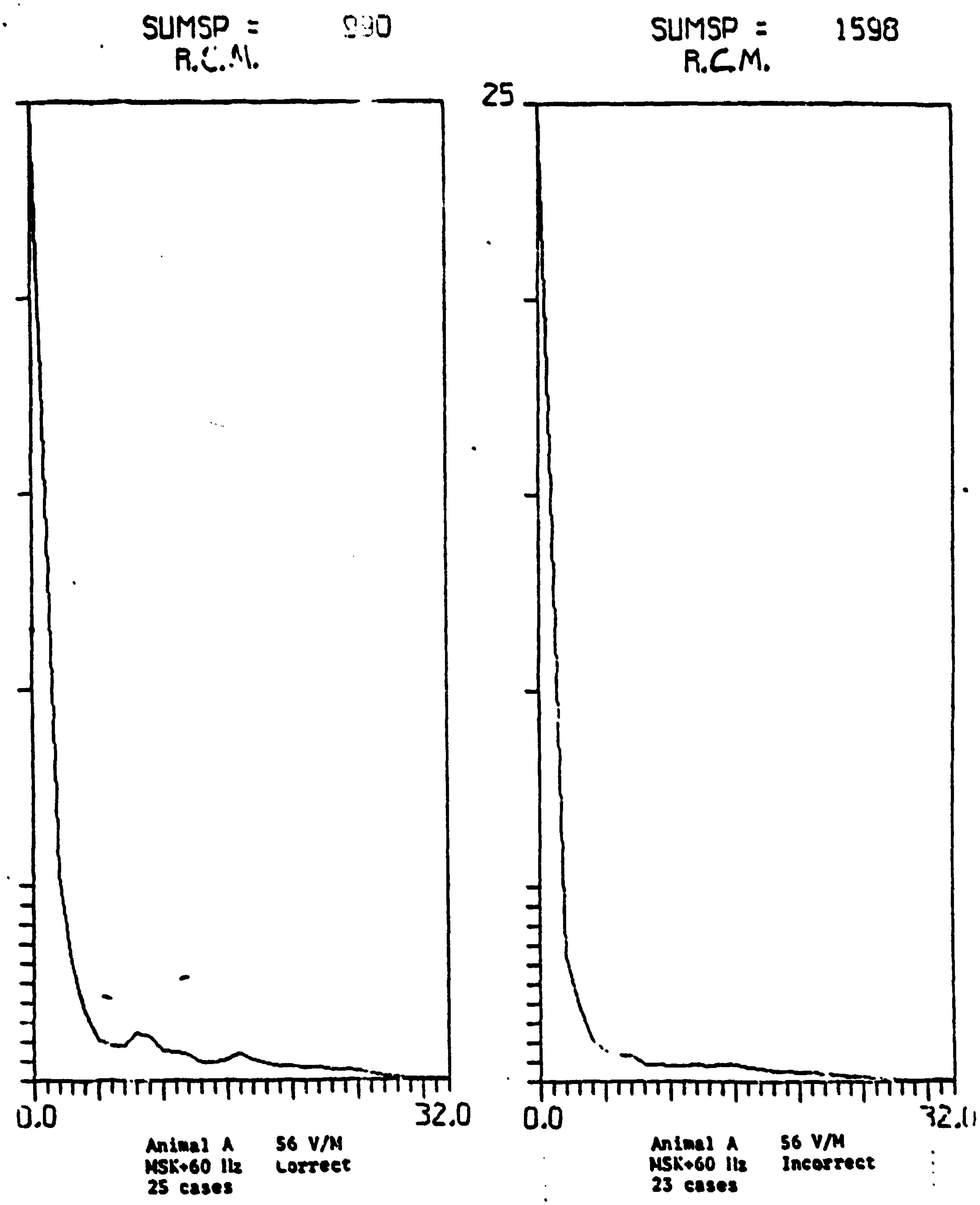
SUMSP : 937
RCM



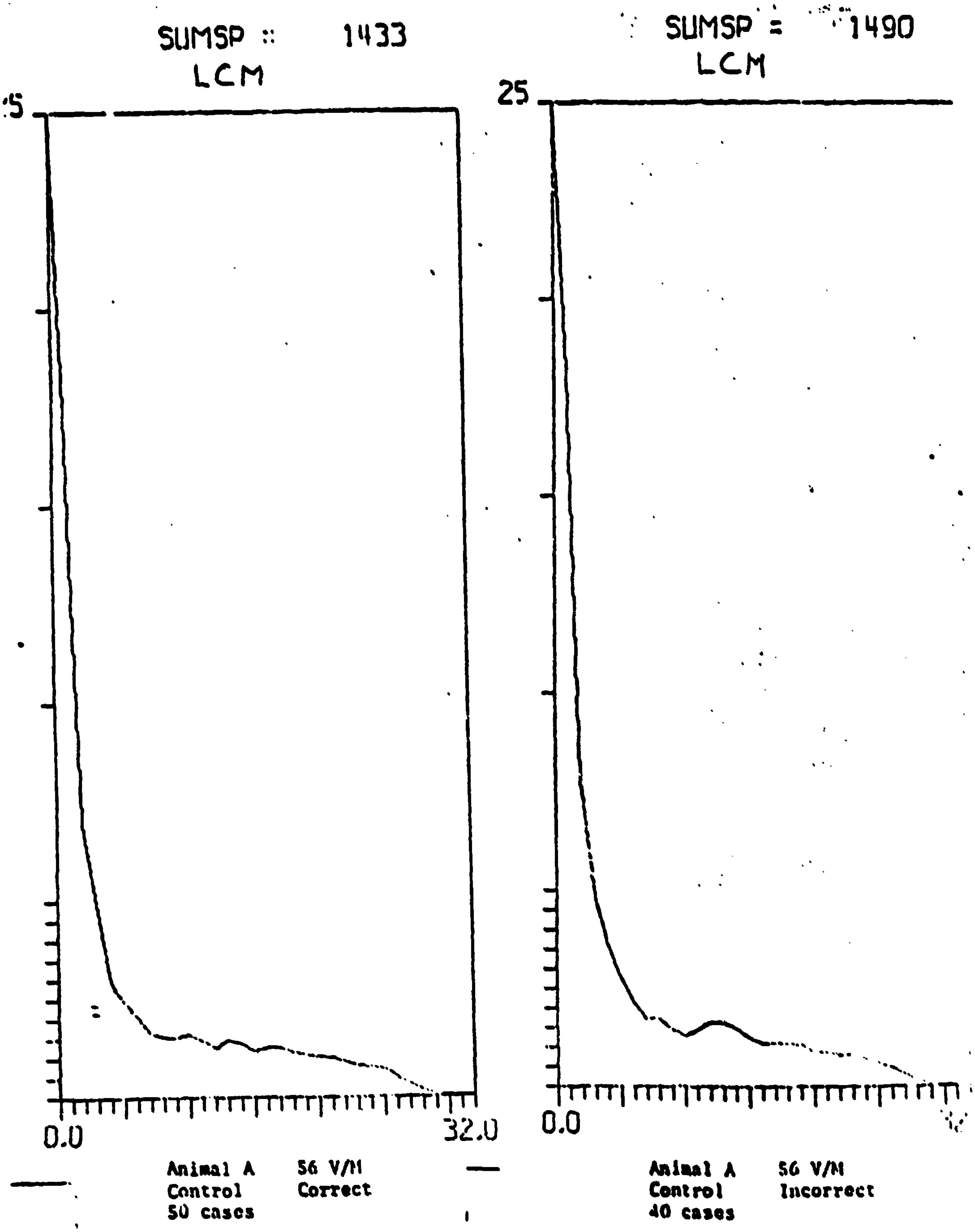
Animal A 76 Hz 18 cases
56 V/M Incorrect

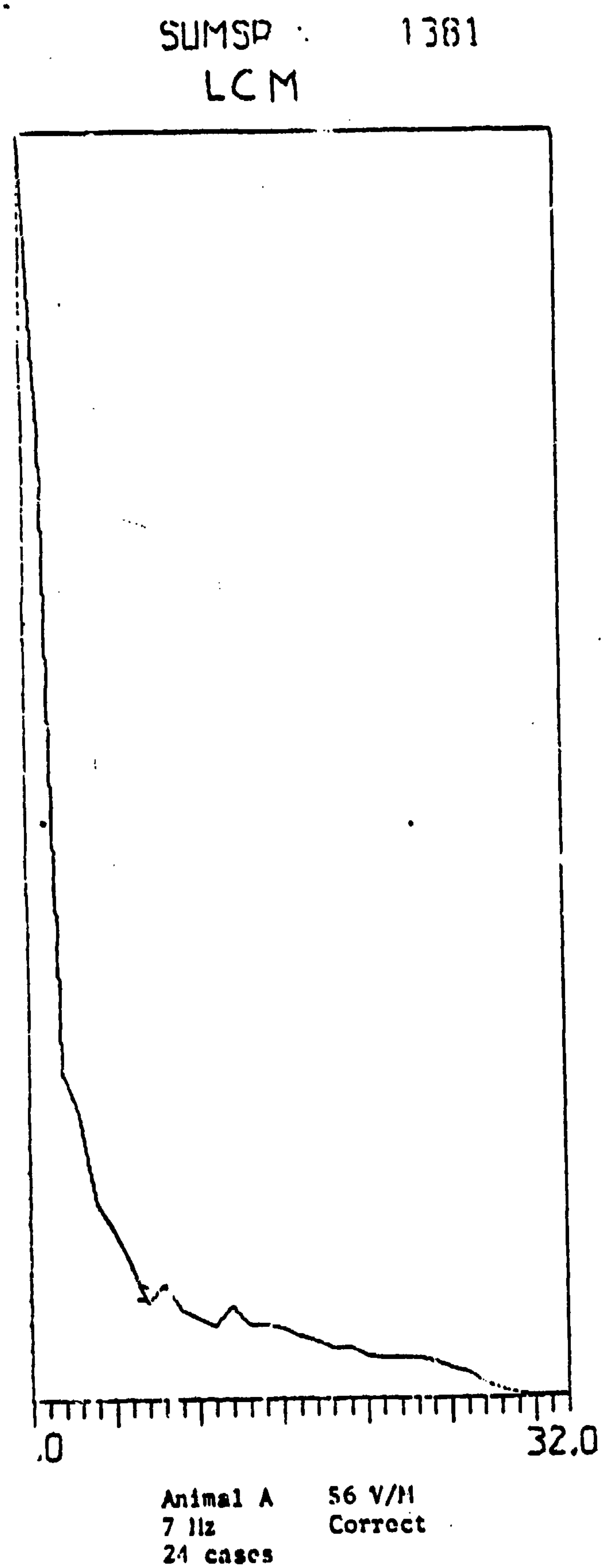

SUMSP : 1511
RCM
.0
32.0
Animal A
MSK
24 cases
56 V/M
Correct

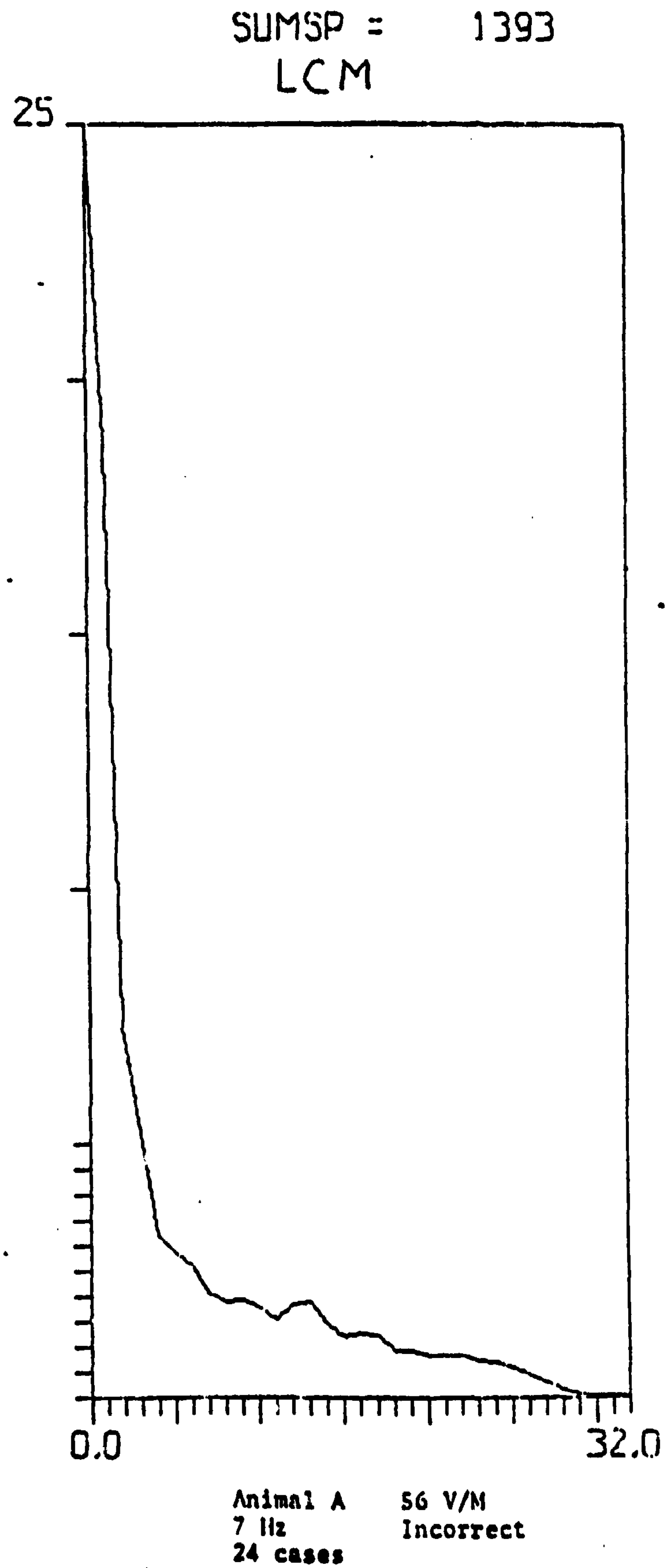

SUMSP : 1053
RCM
25
0.0
32.0
Animal A
MSK
15 cases
56 V/M
Incorrect

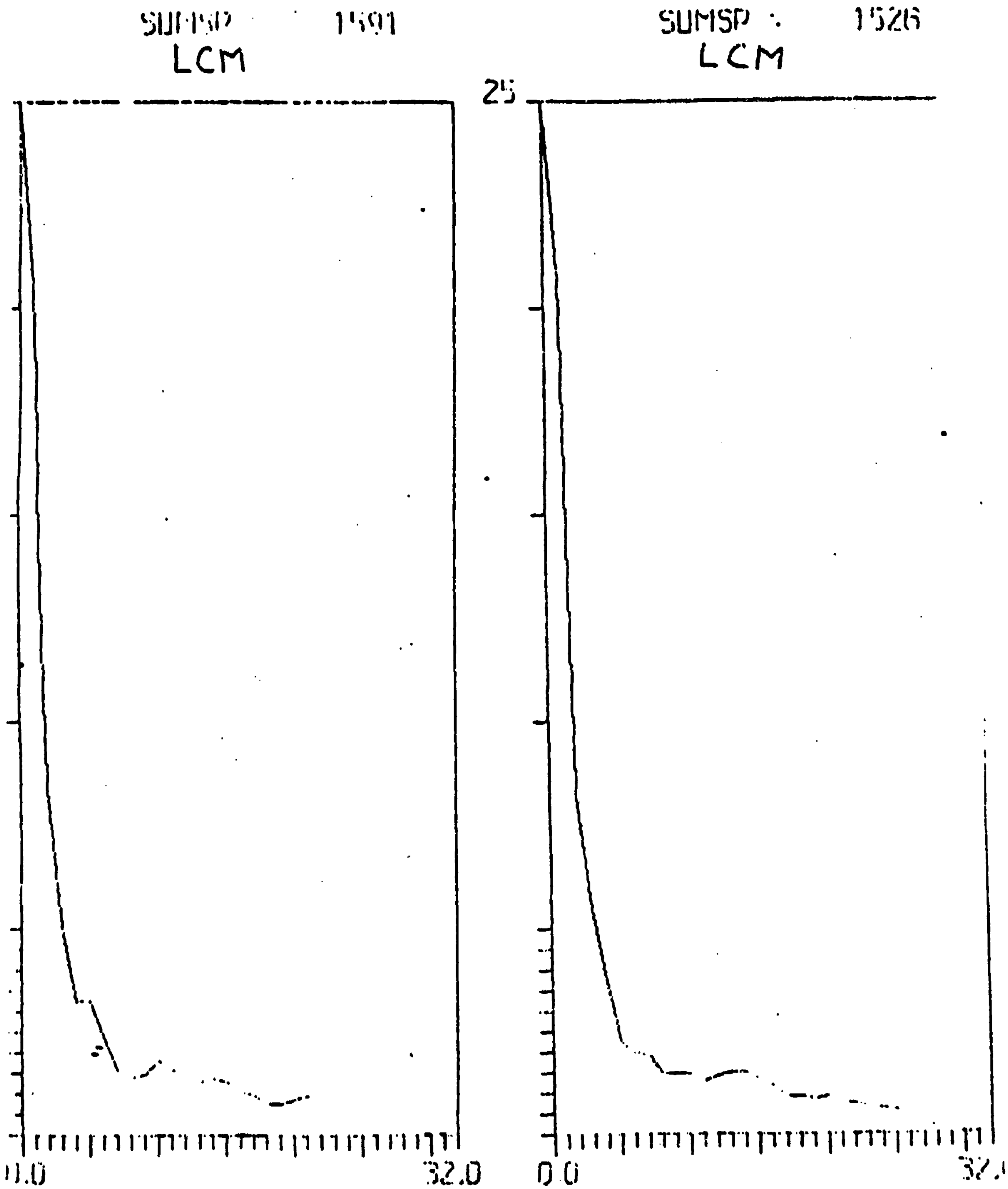


SUMSP = 990
R.C.M.
0.0
32.0
Animal A 56 V/M
MSK+60 Hz Correct
25 cases
SUMSP = 1598
R.C.M.
25
0.0
Animal A 56 V/M
MSK+60 Hz Incorrect
23 cases


SUMSP :: 1433
LCM
0.0
32.0
Animal A
Control
50 cases
56 V/M
Correct
SUMSP = 1490
LCM
25
0.0
Animal A
Control
40 cases
56 V/M
Incorrect

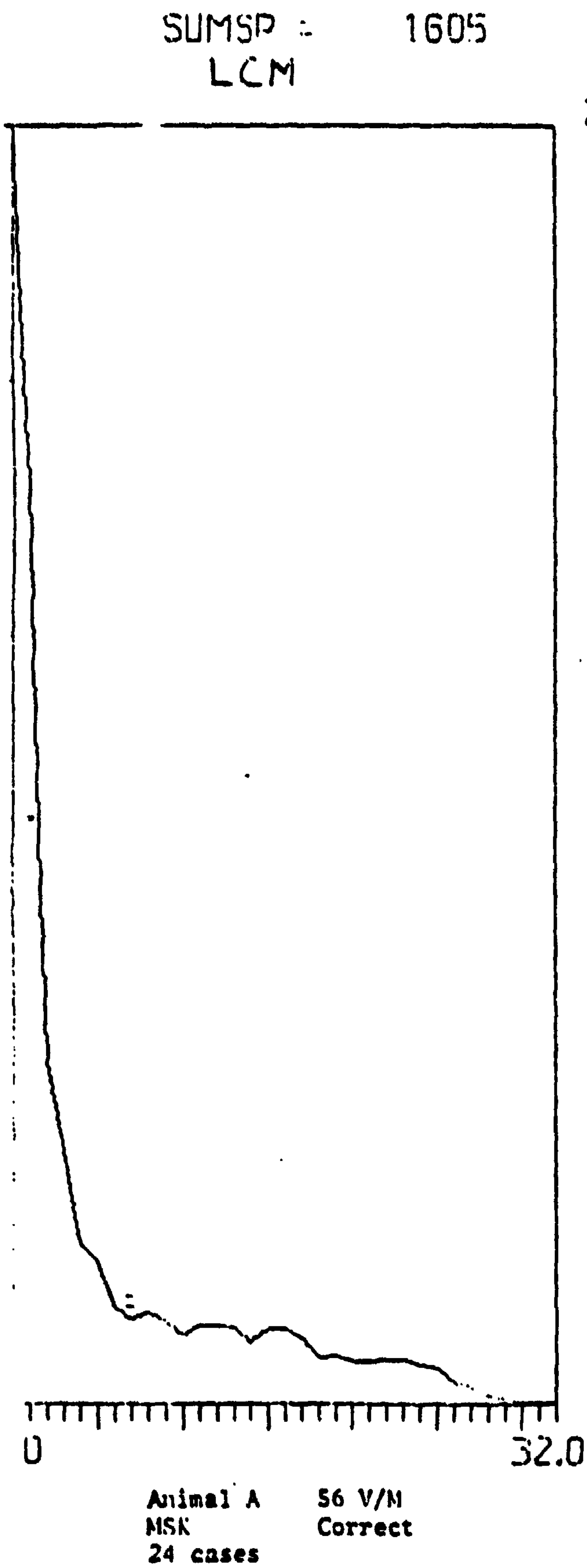

SUMSP : 1381
LCM
.0
32.0
Animal A
7 Hz
24 cases
56 V/M
Correct

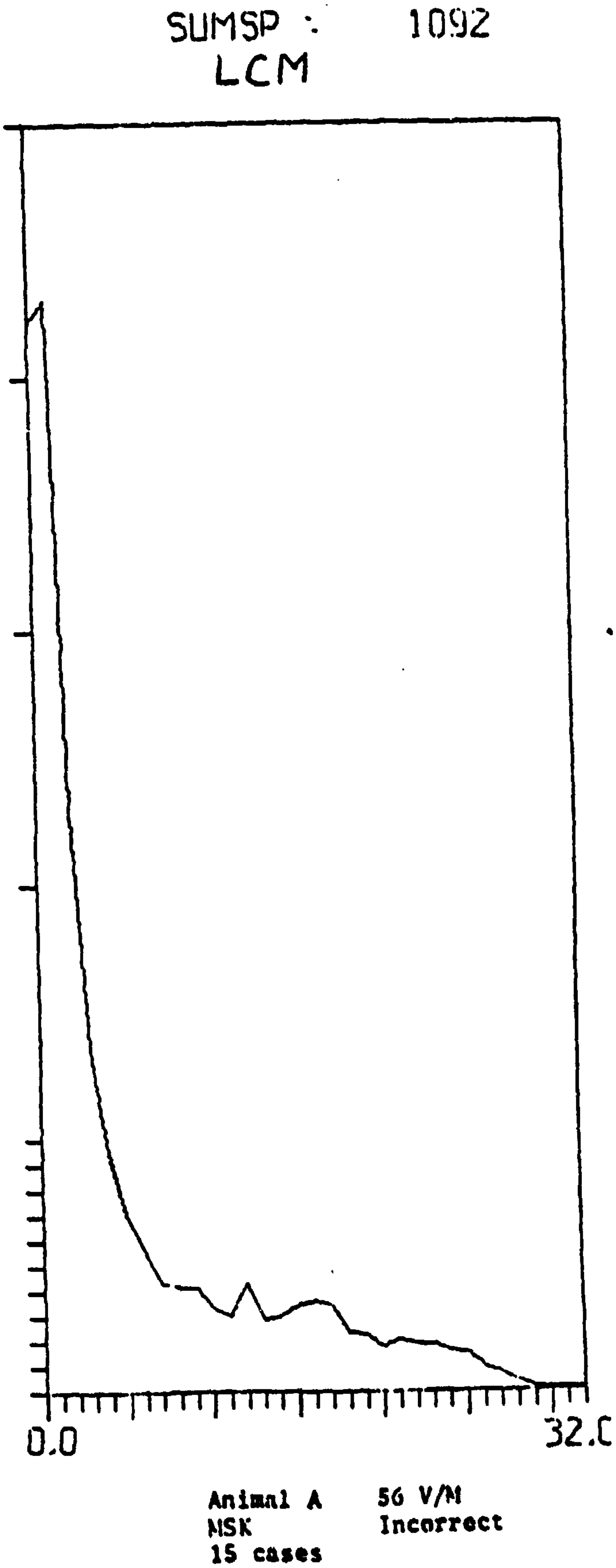

SUMSP = 1393
LCM
25
0.0
32.0
Animal A
7 Hz
24 cases
56 V/M
Incorrect

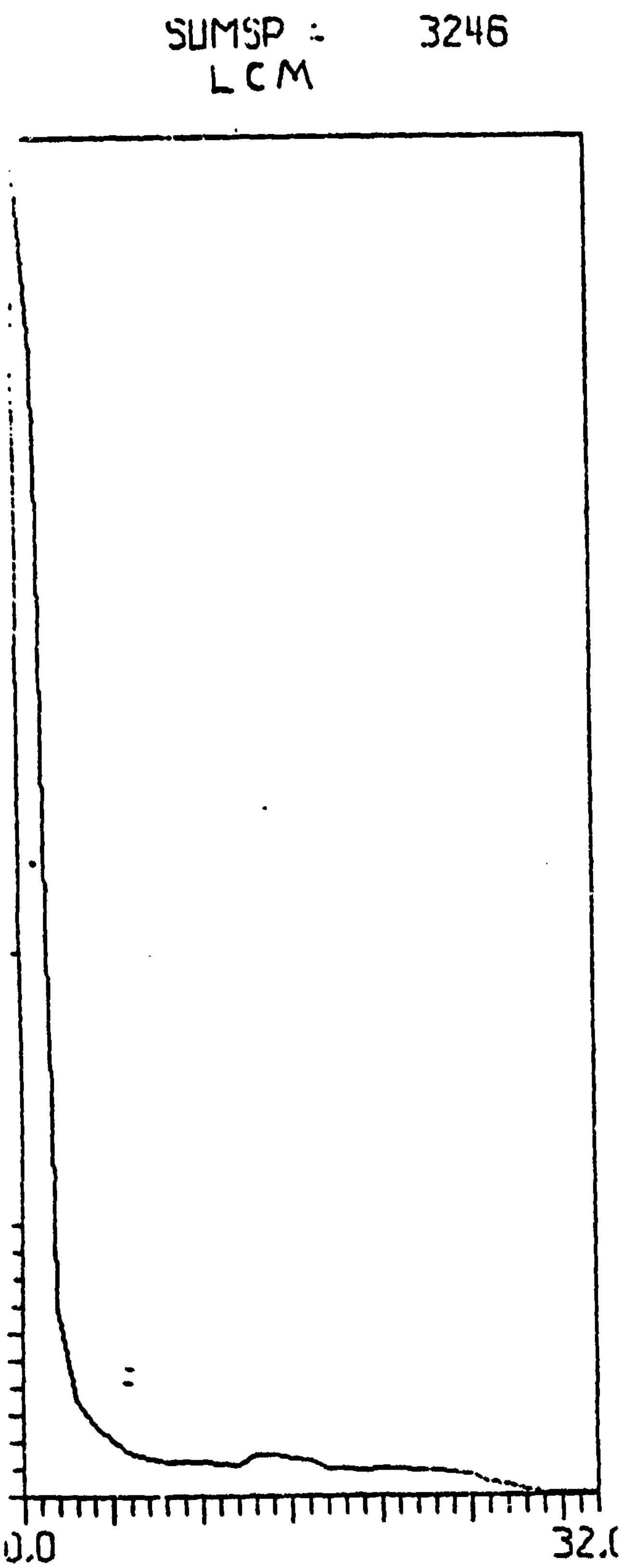


Animal A 56 V/M
76 Hz Correct
17 cases

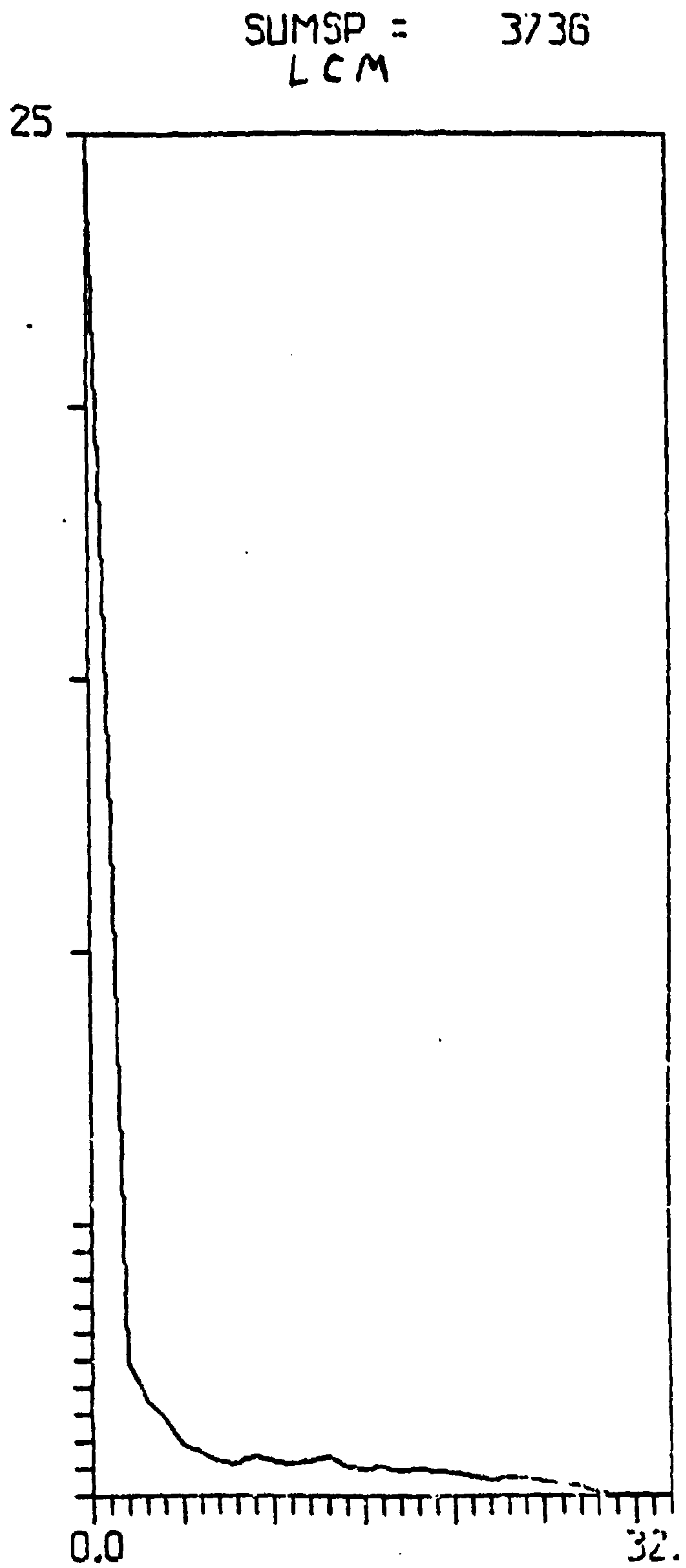
Animal A 56 V/M
76 Hz Incorrect
18 cases


SUMSP : 1605
LCM
0
32.0
Animal A 56 V/M
MSK Correct
24 cases

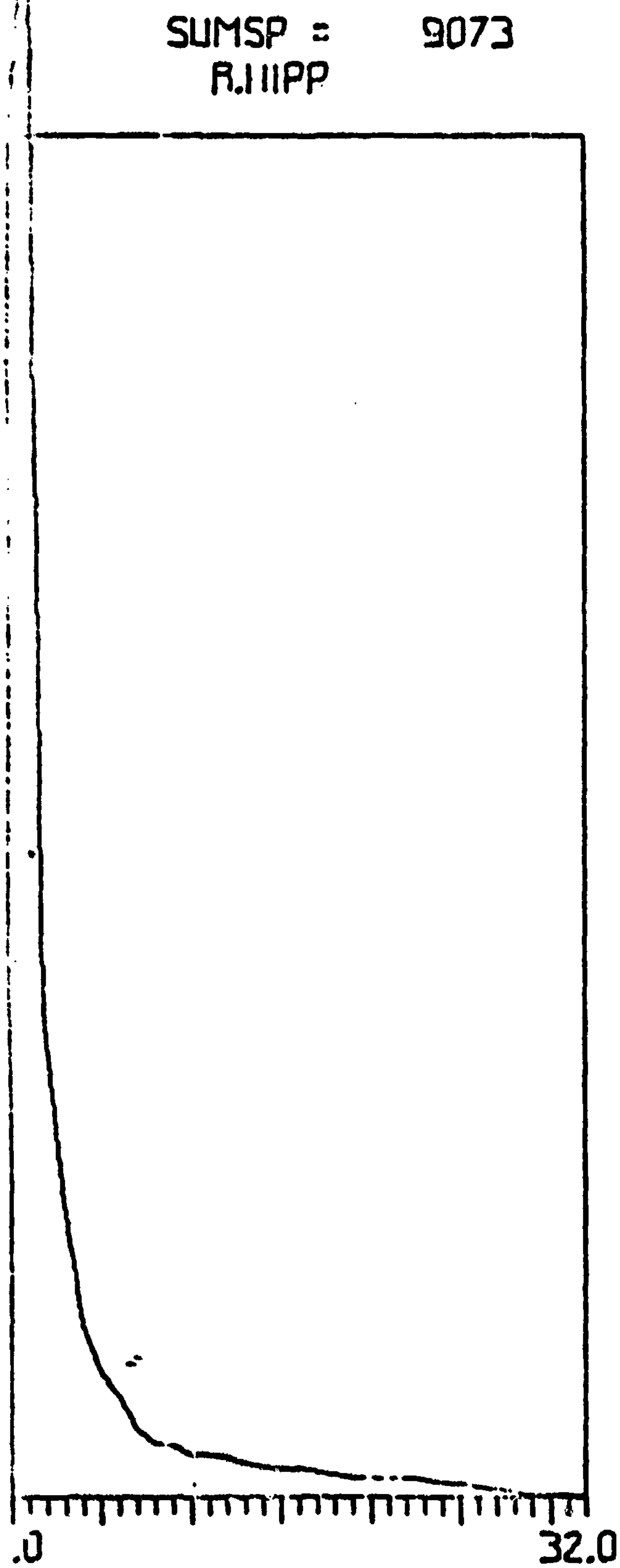

SUMSP : 1092
LCM
25
0.0
32.0
Animal A 56 V/M
MSK Incorrect
15 cases



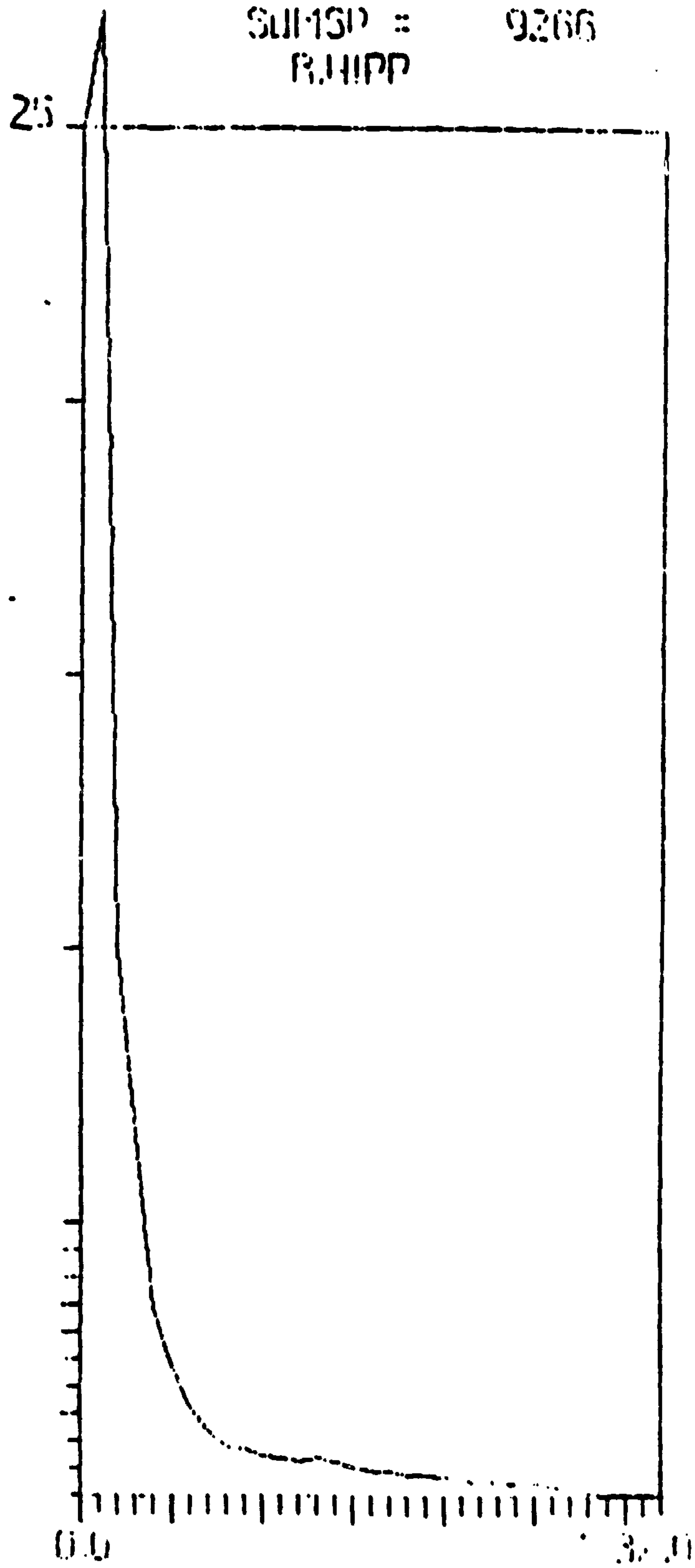
Animal A 56 V/M
MSK+60 Hz Correct
25 cases



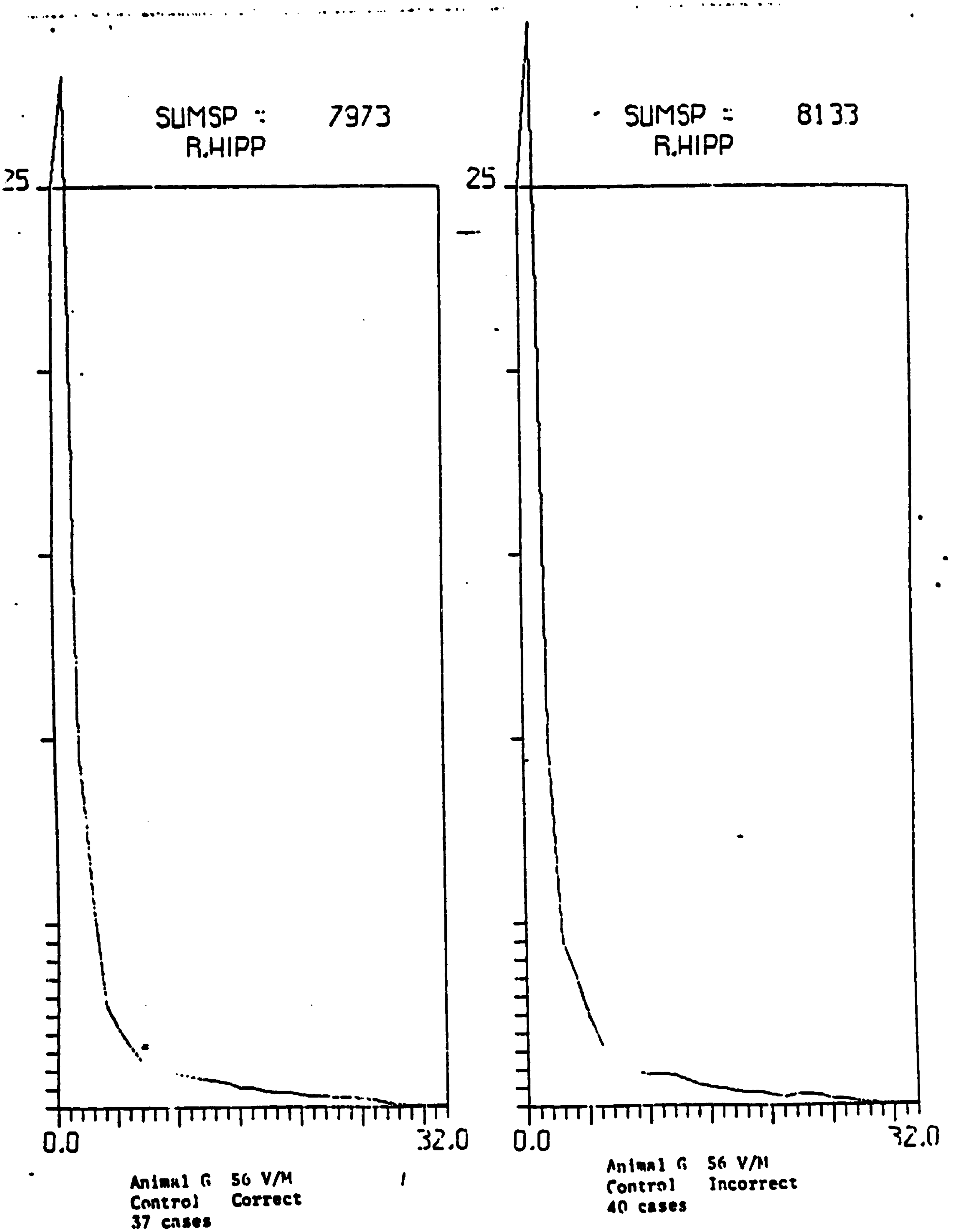
Animal A 56 V/M
MSK+60 Hz Incorrect
23 cases



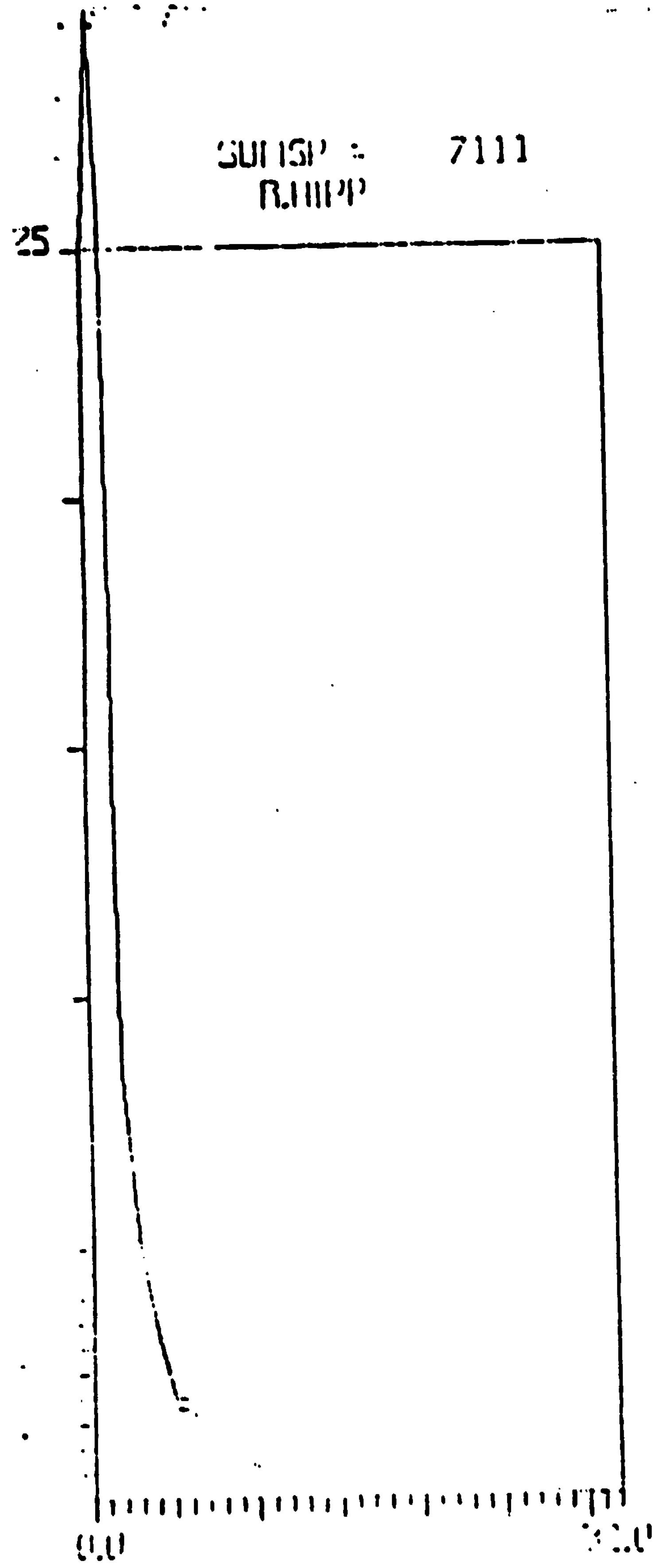
Animal G 10 V/M
Control Correct
47 cases



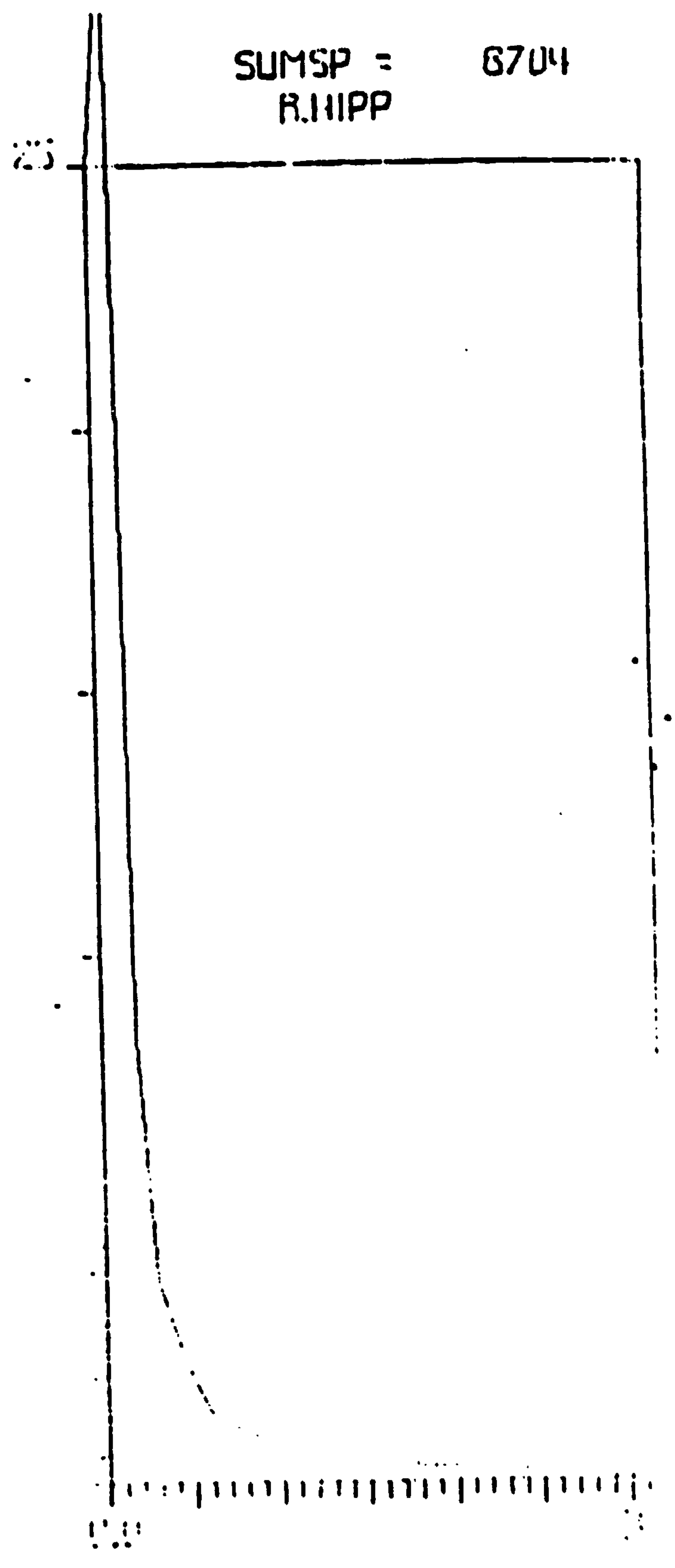
Animal G 10 V/M
Control Incorrect
47 cases



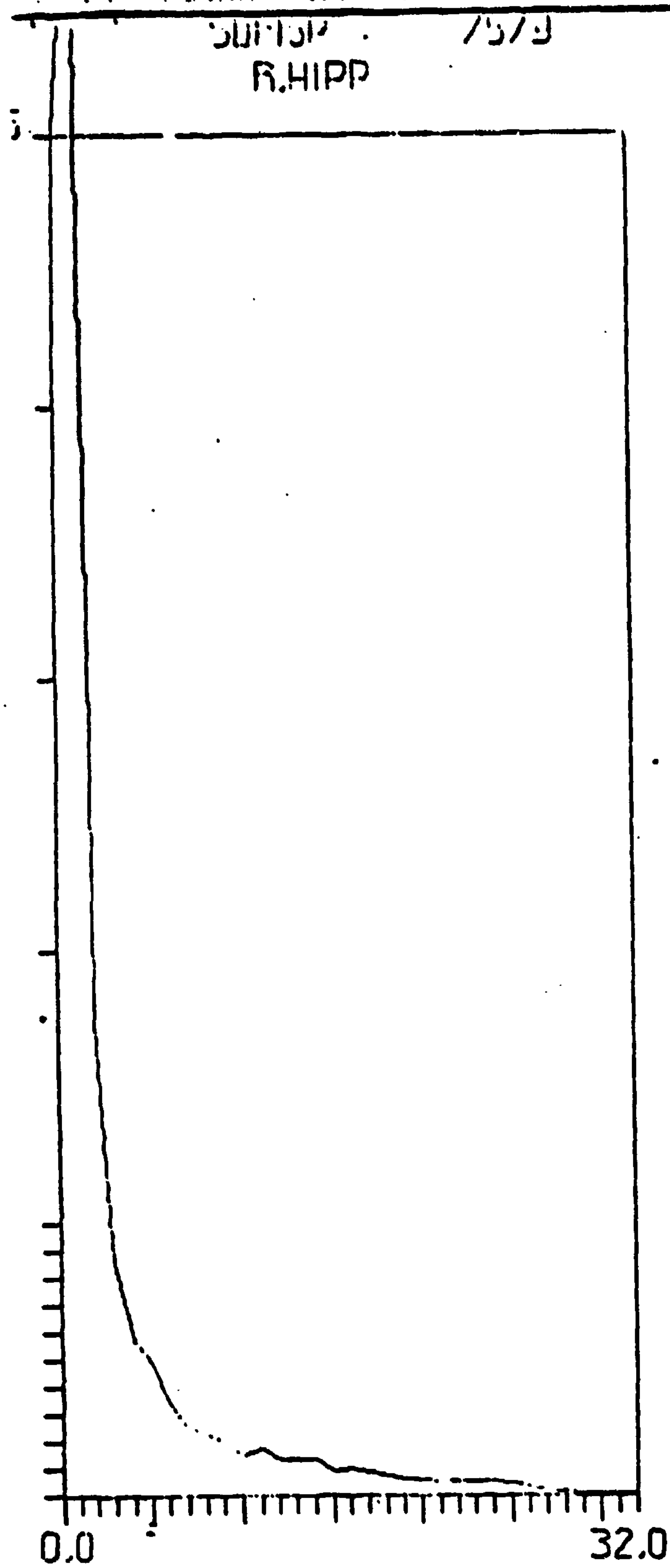
SUMSP = 7973
R.HIPP
25
0.0
32.0
Animal G 56 V/M
Control Correct
37 cases
SUMSP = 8133
R.HIPP
25
0.0
32.0
Animal G 56 V/M
Control Incorrect
40 cases



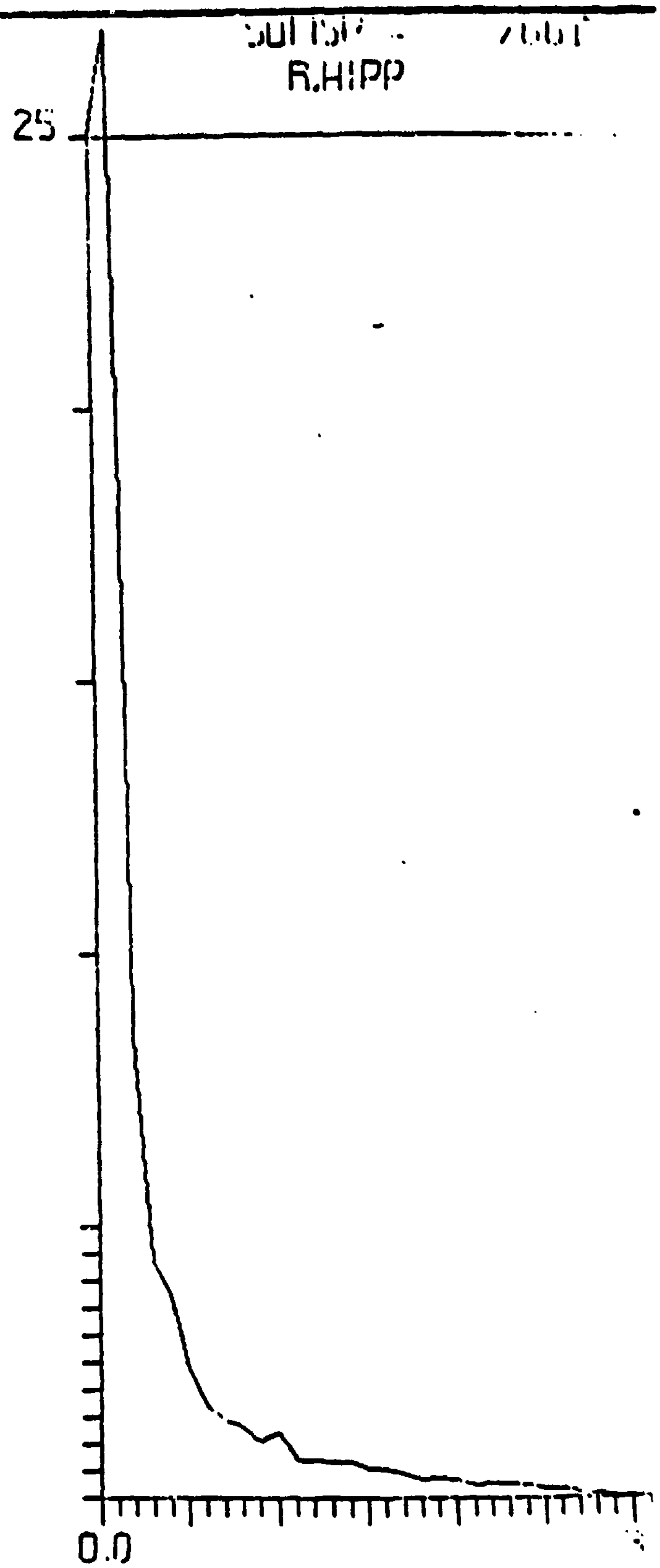
Animal G 10 V/M
7 Hz Correct
22 cases



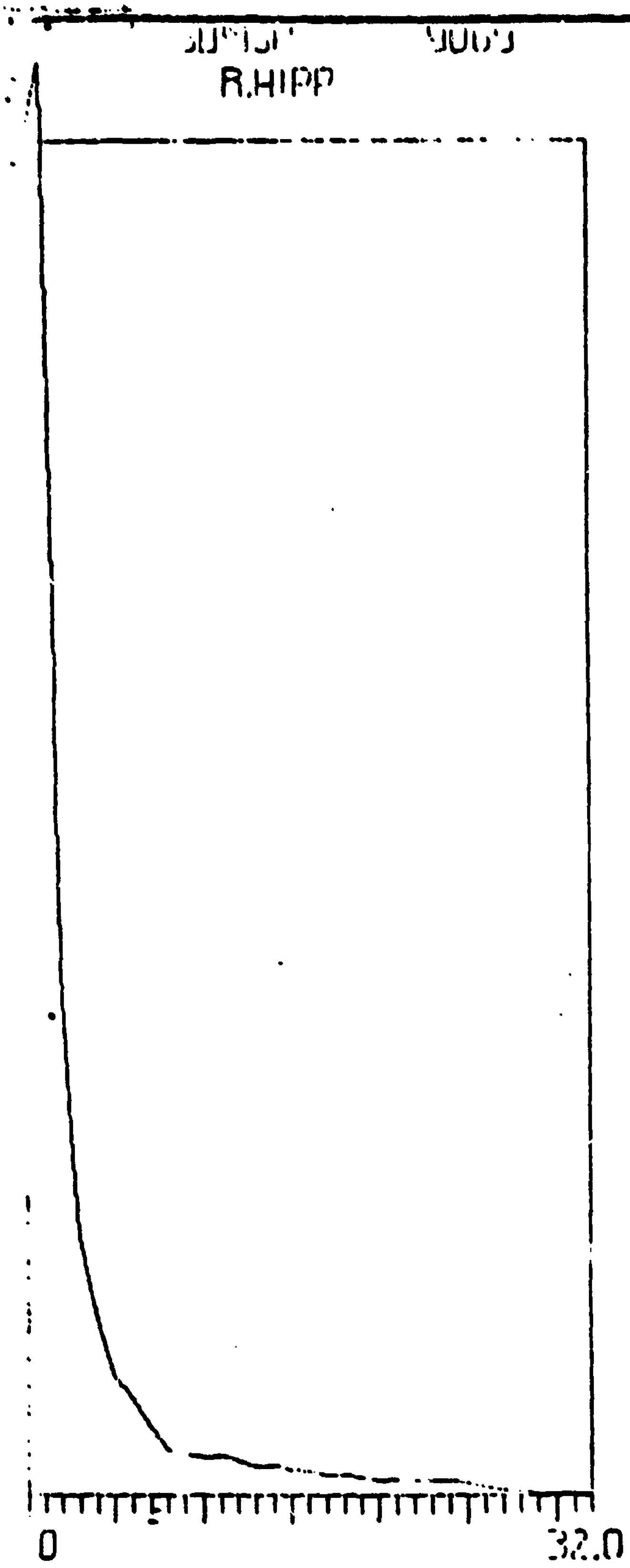
Animal G 10 V/M
7 Hz Incorrect
23 cases



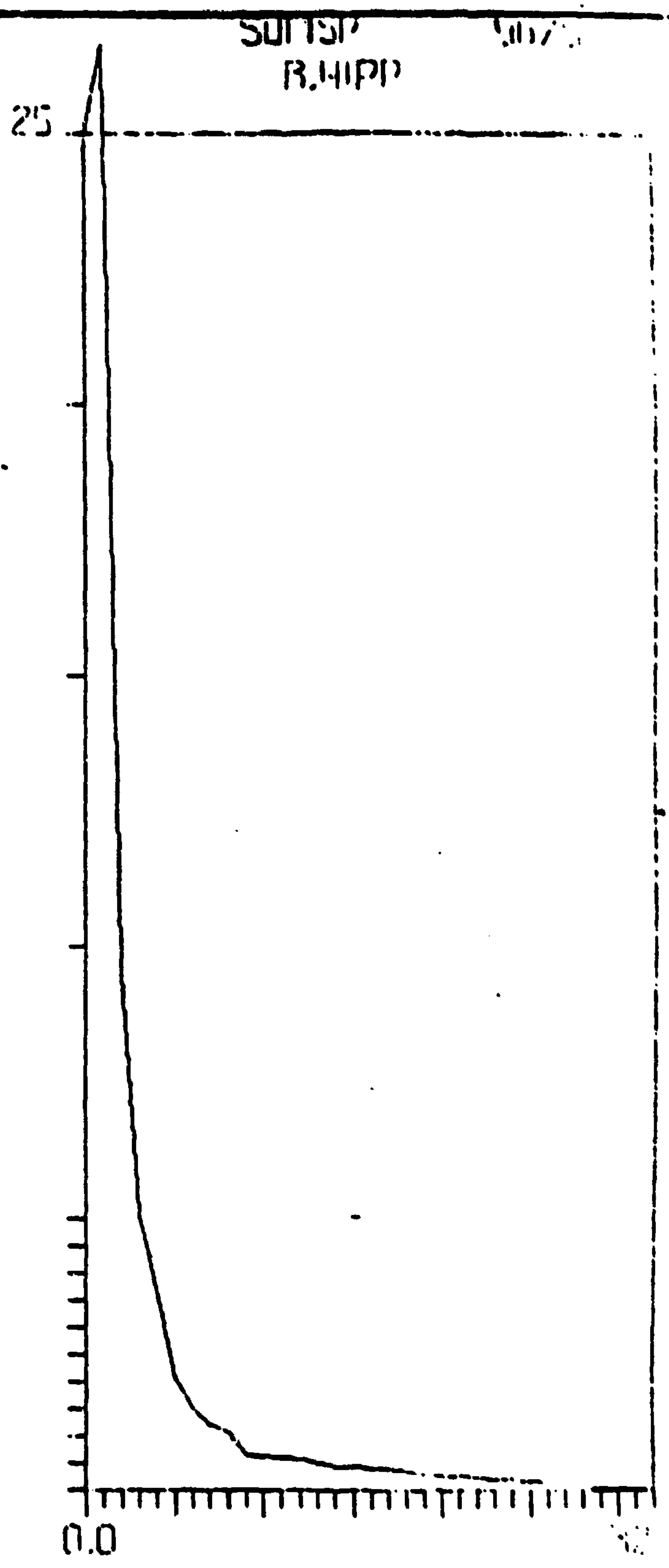
Animal G 56 V/M
7 Hz Correct
12 cases



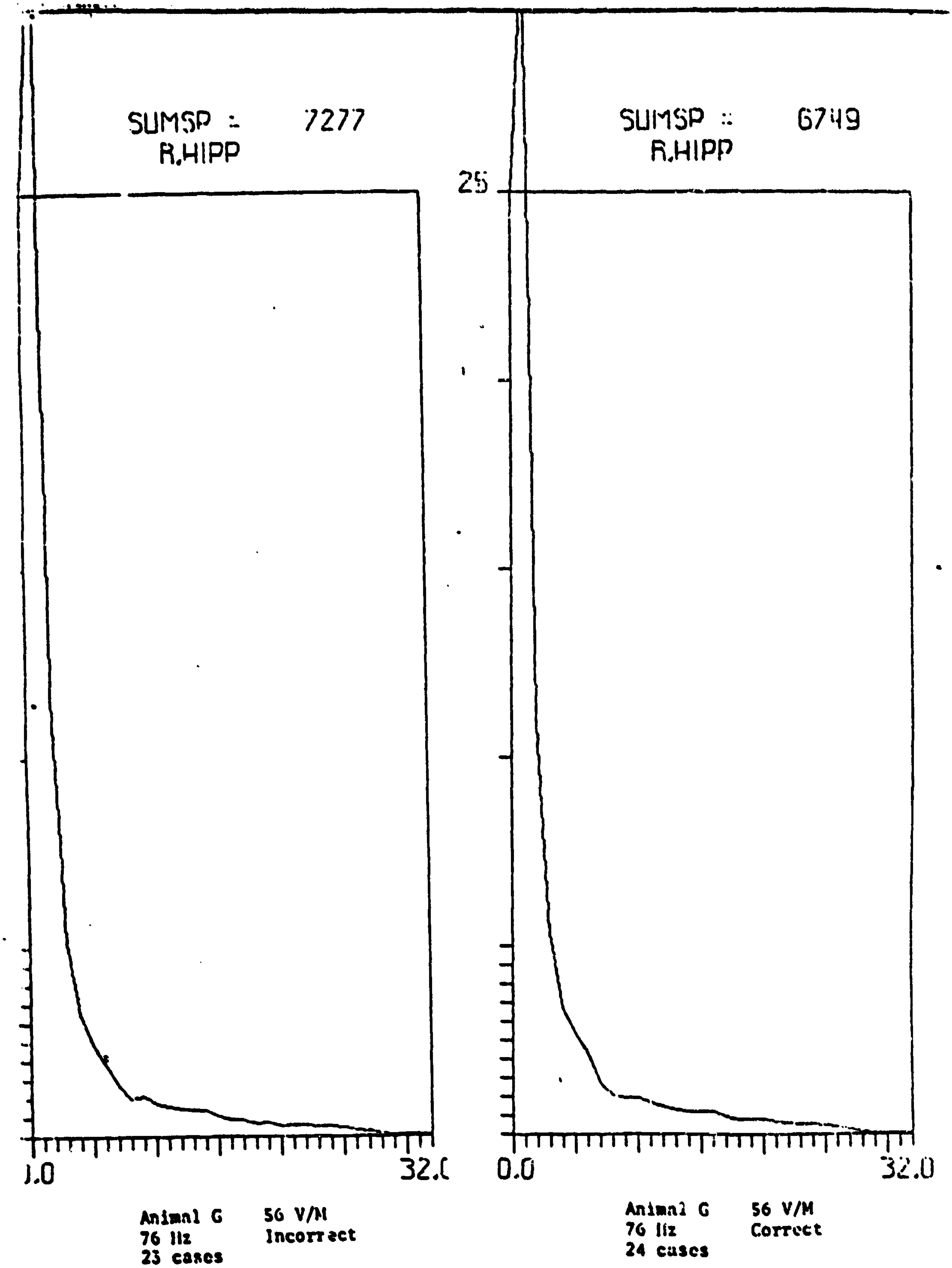
Animal G 56 V/M
7 Hz Incorrect
12 cases



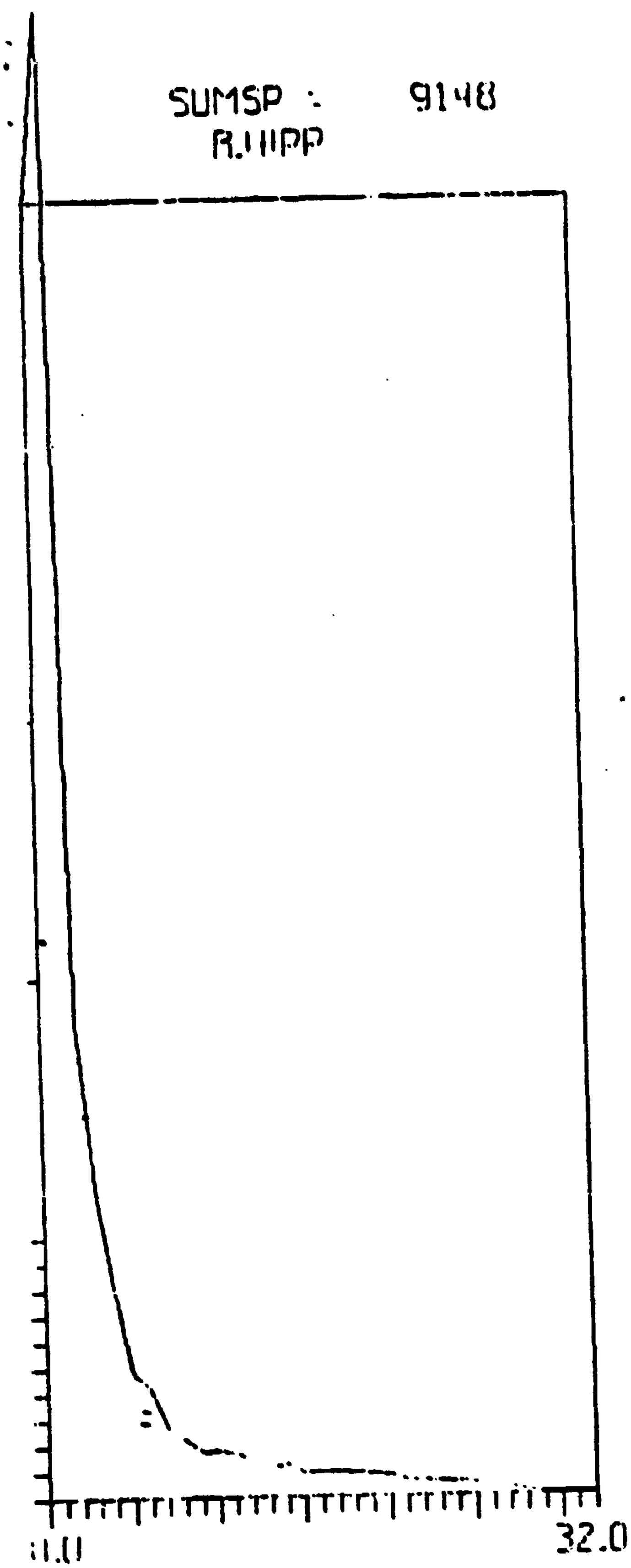
Animal G 10 V/M
76 Hz Correct
24 cases



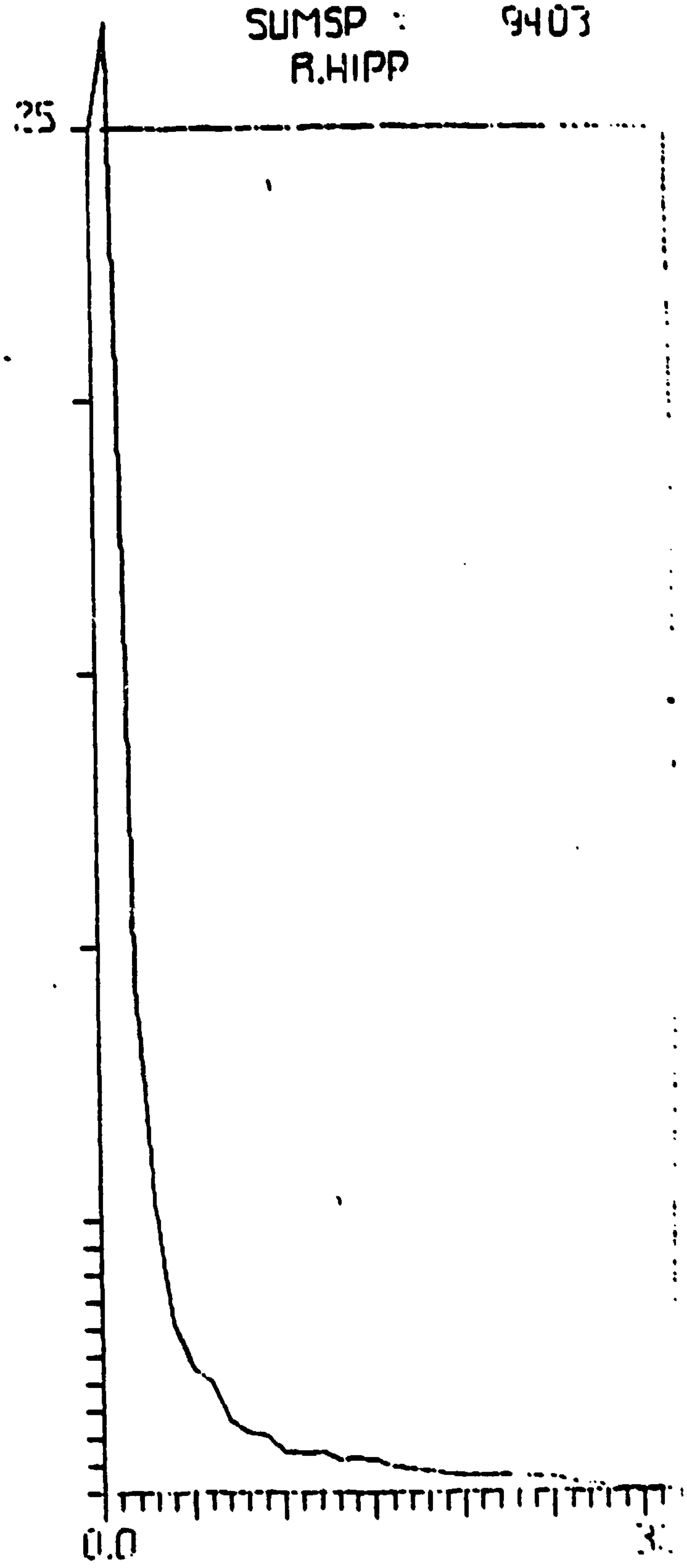
Animal G 10 V/M
76 Hz Incorrect
24 cases



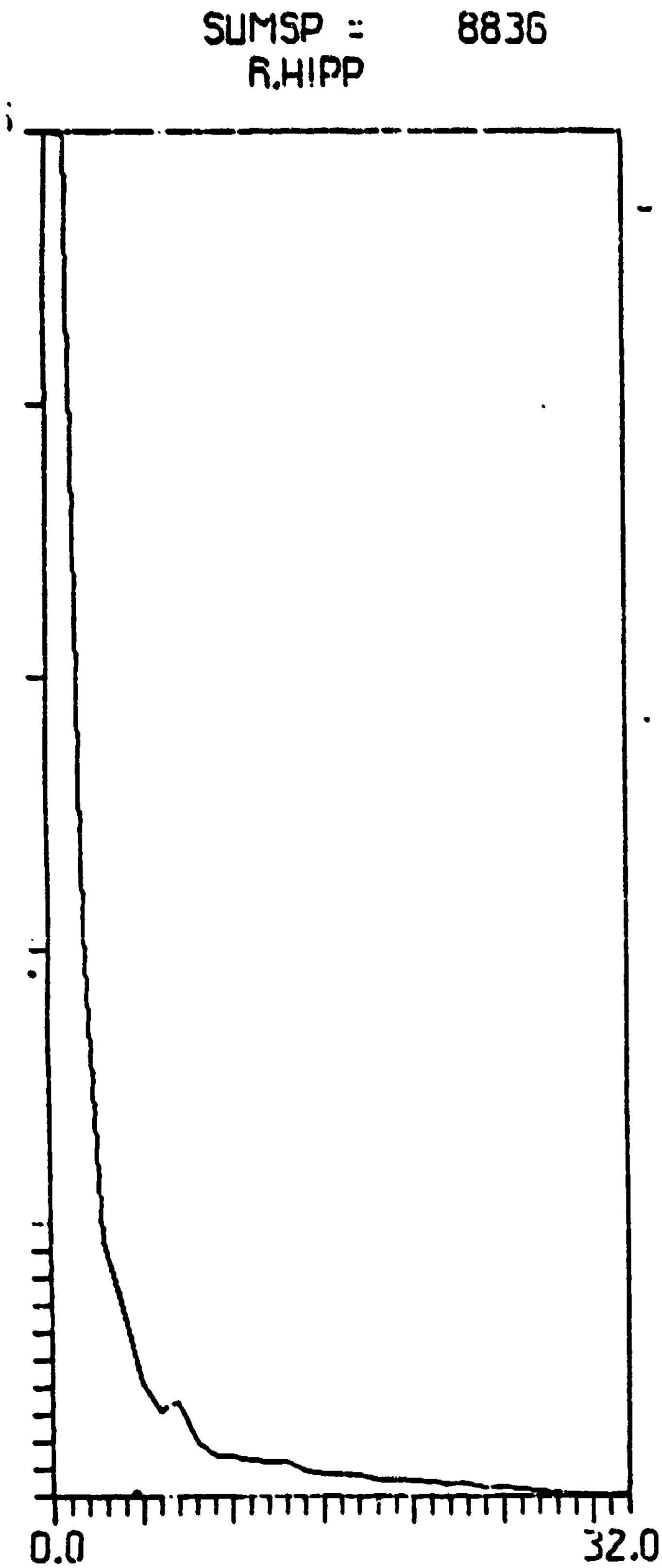
SUMSP : 7277
R.HIPP
SUMSP : 6749
R.HIPP
25
J.0
32.(
0.0
32.0
Animal G 56 V/M
76 Hz Incorrect
23 cases
Animal G 56 V/M
76 Hz Correct
24 cases



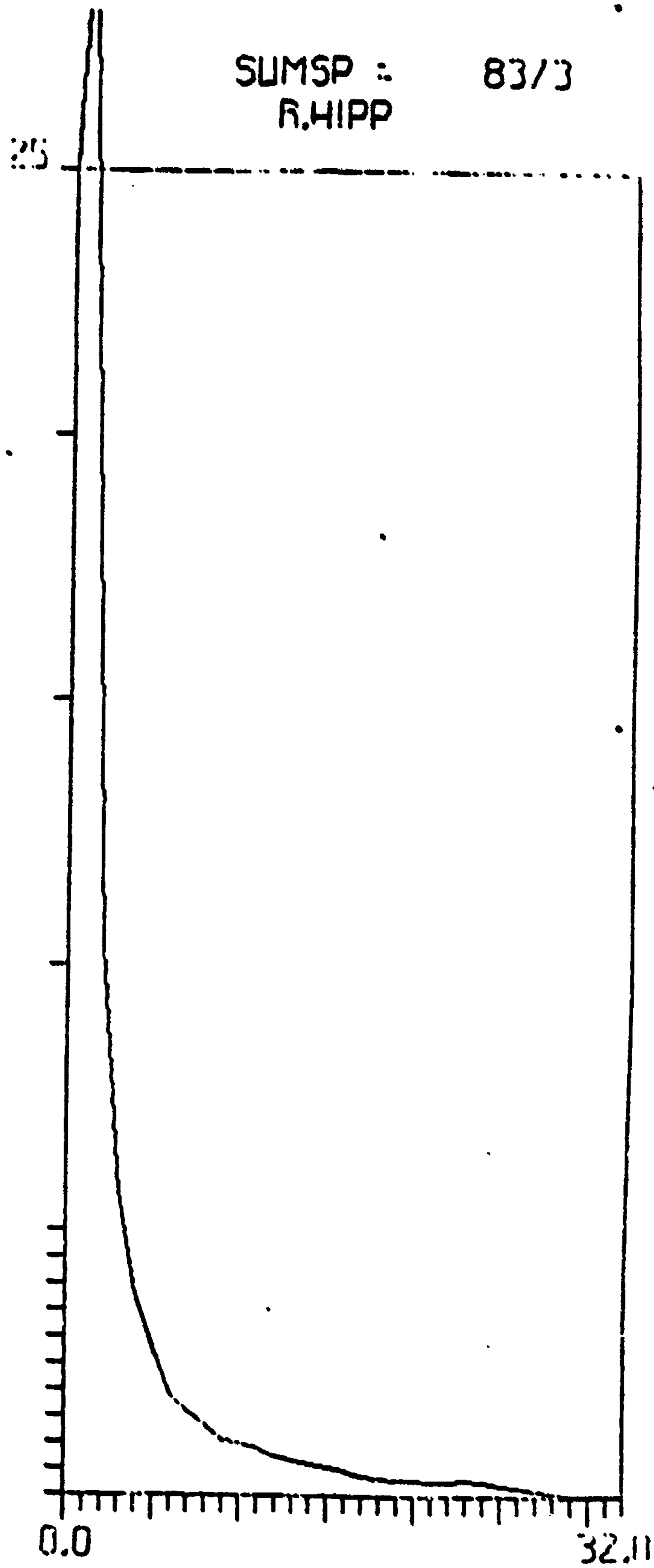
Animal G 10 V/M
MSK Correct
24 cases



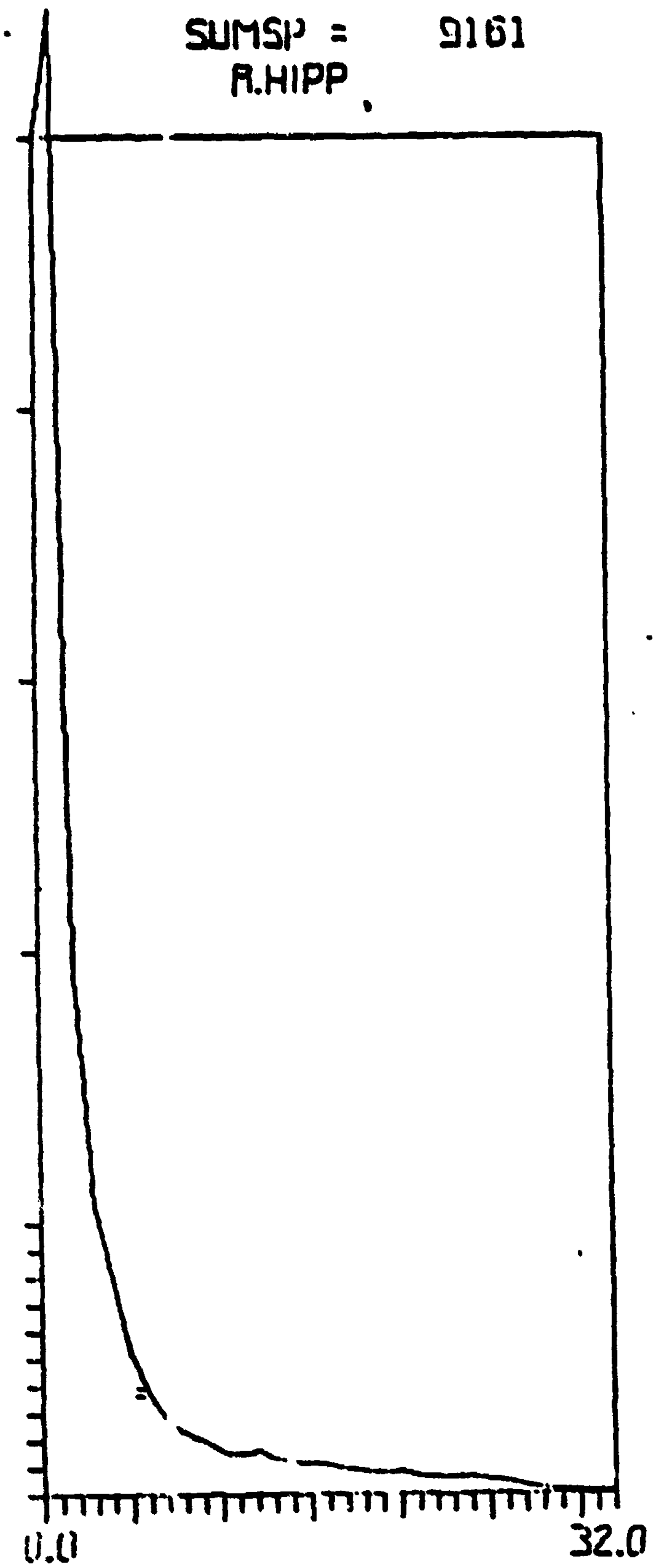
Animal G 10 V/M
MSK Incorrect
24 cases



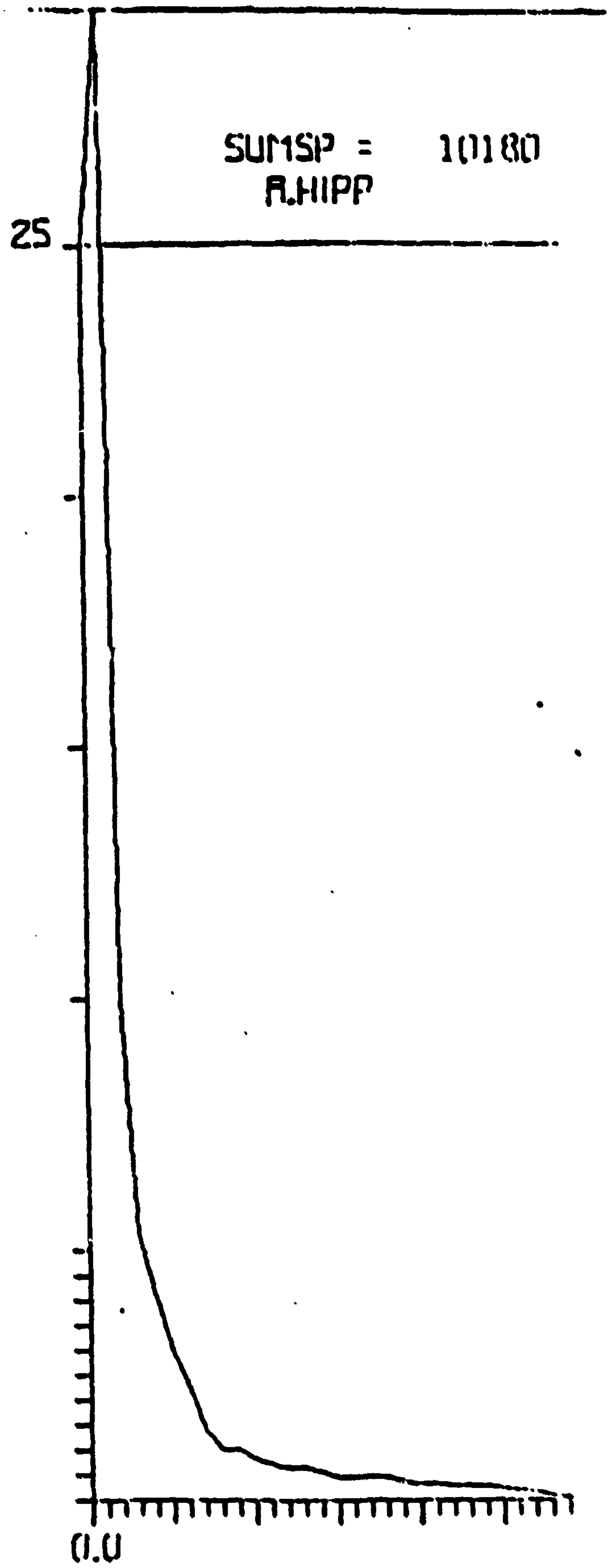
Animal G 56 V/M
MSK Correct
21 cases



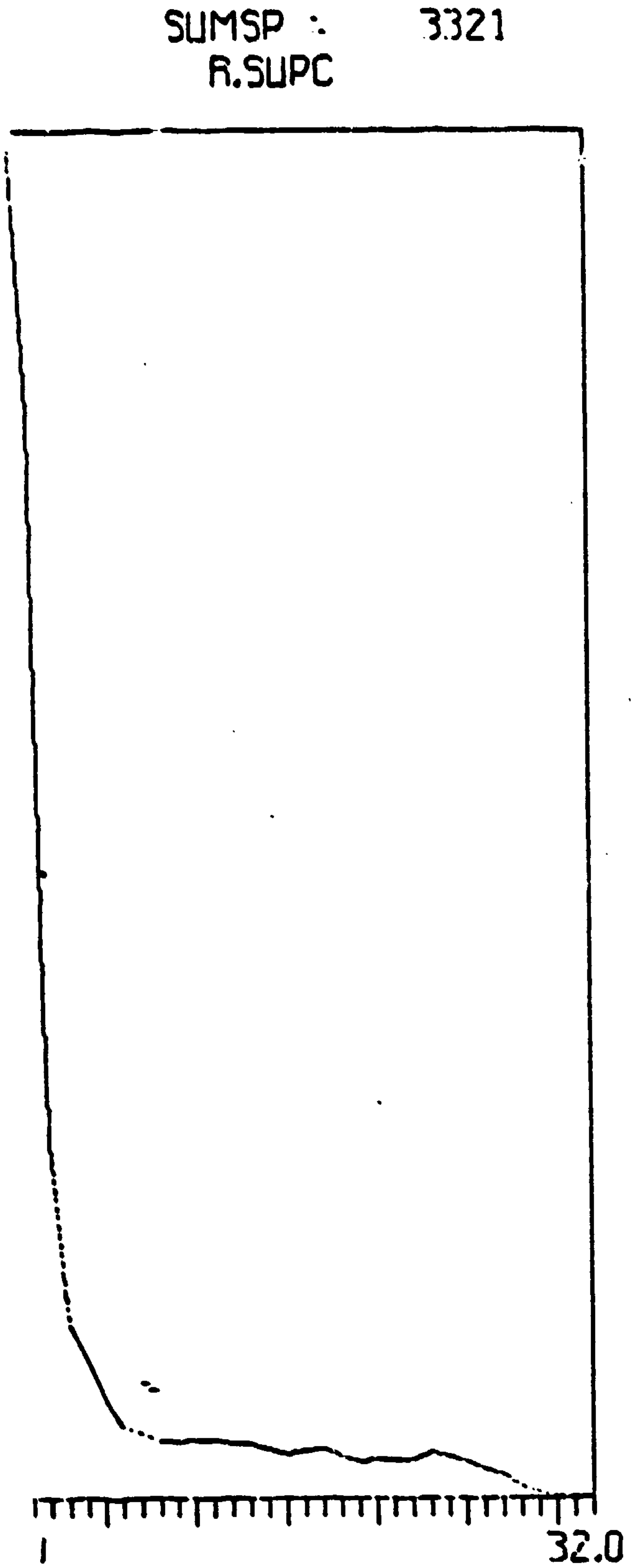
Animal G 56 V/M
MSK Incorrect
13 cases



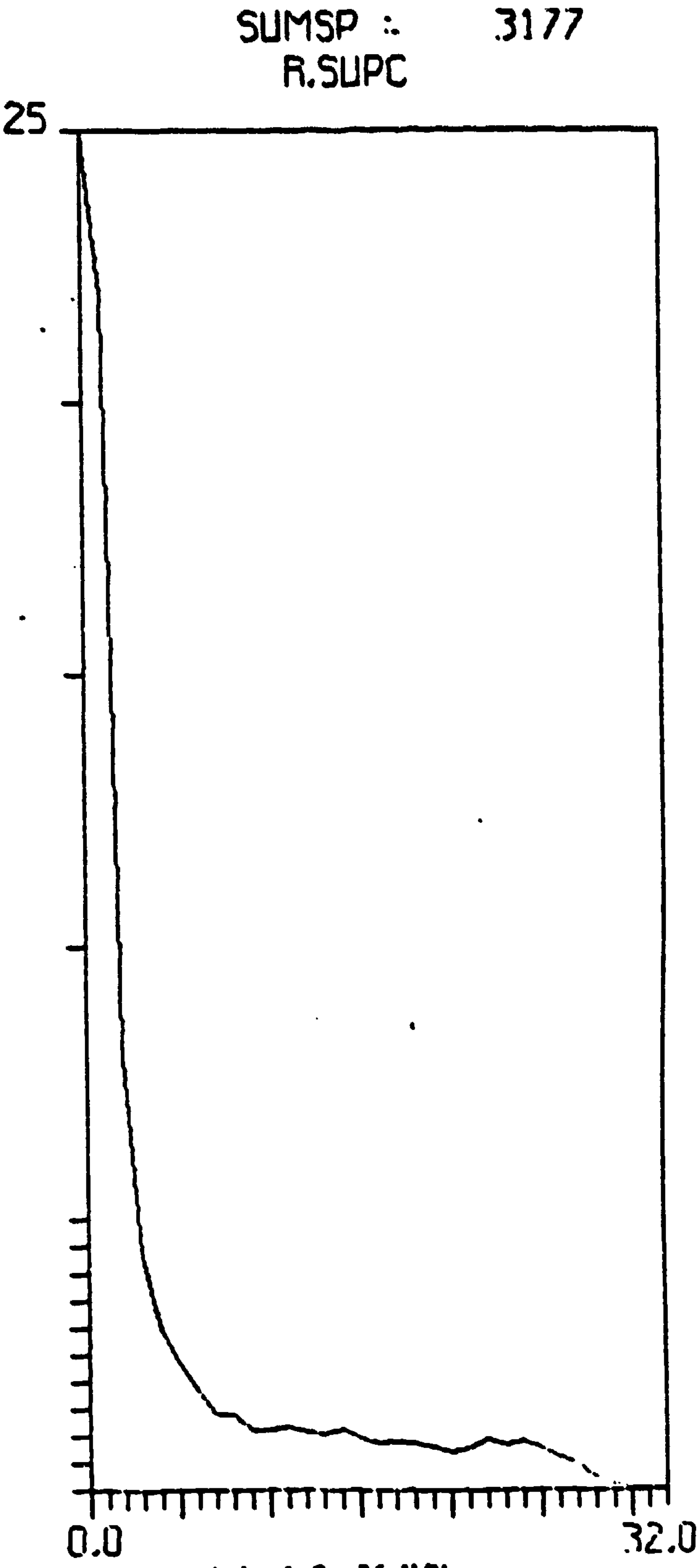
Animal G 10 V/M
MSK+60 Hz Correct
24 cases



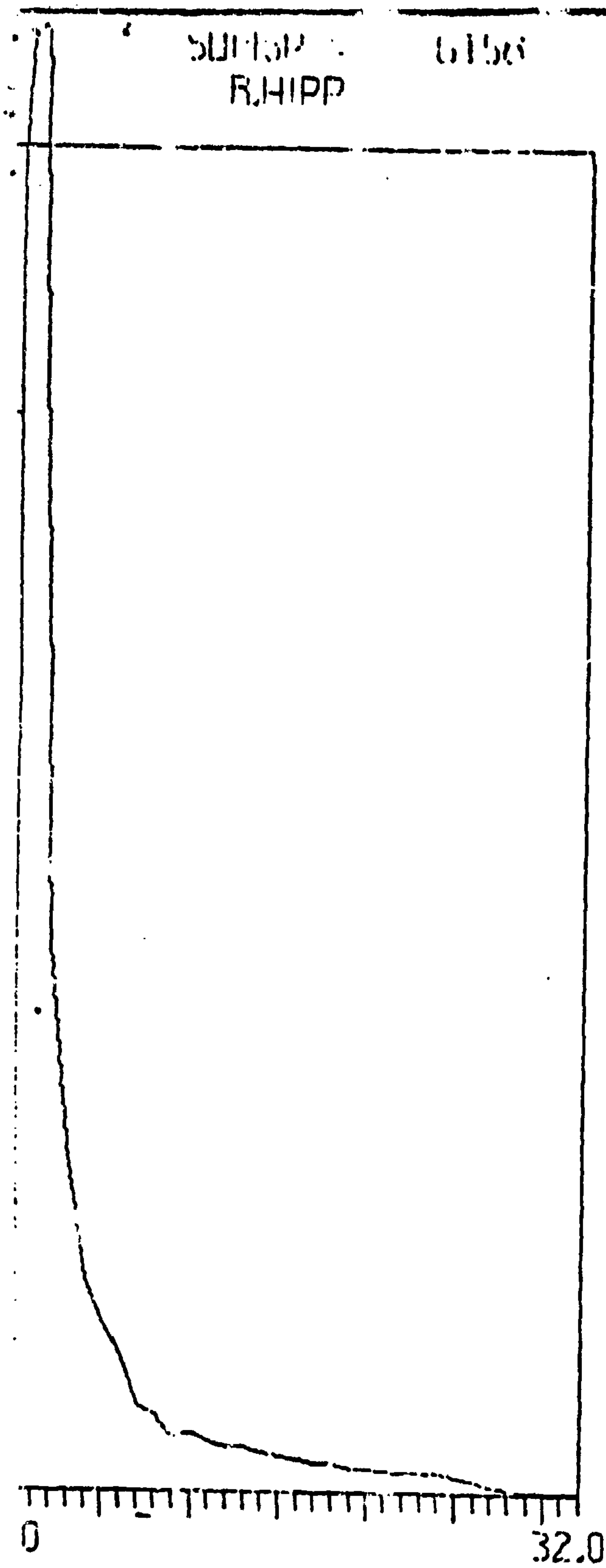
Animal G 10 V/M
MSK+60 Hz Incorrect
24 Cases



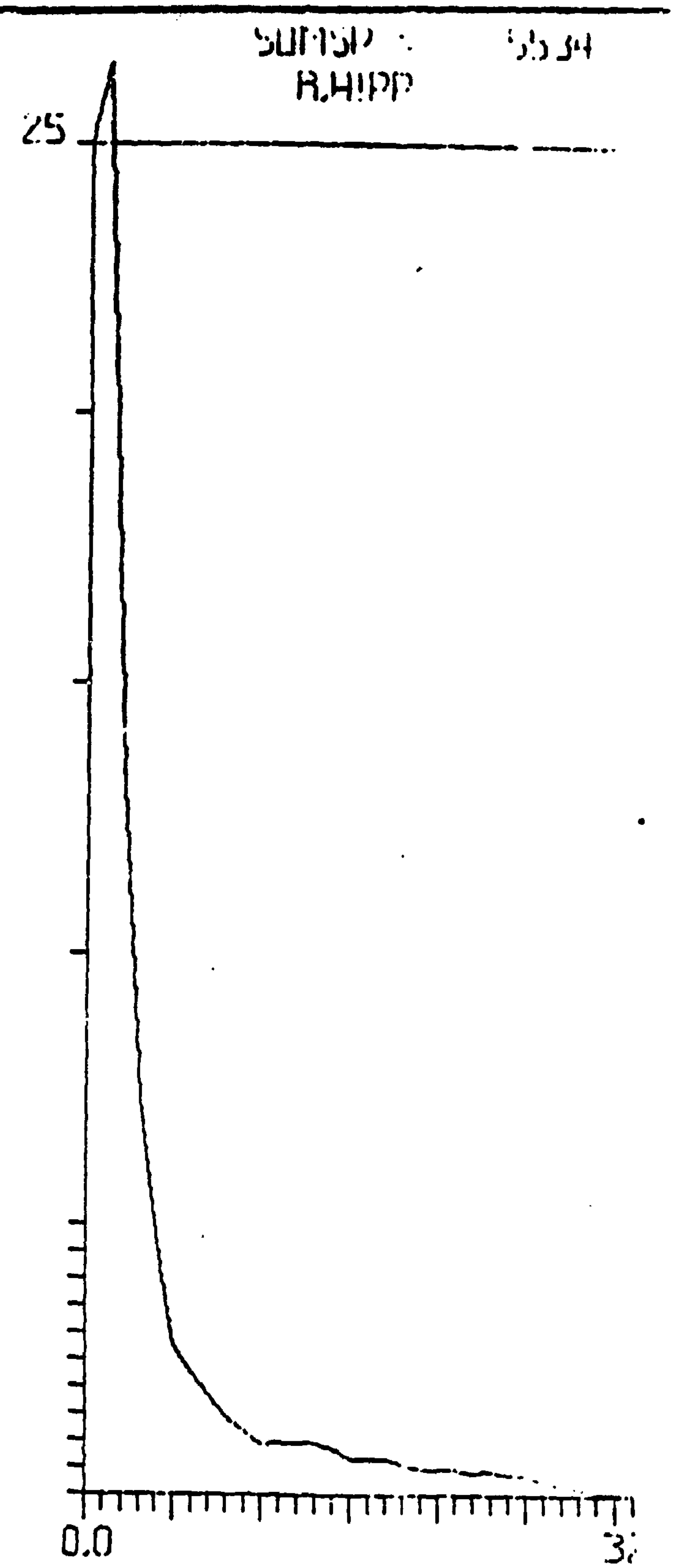
Animal G 56 V/M
Control Correct
37 cases



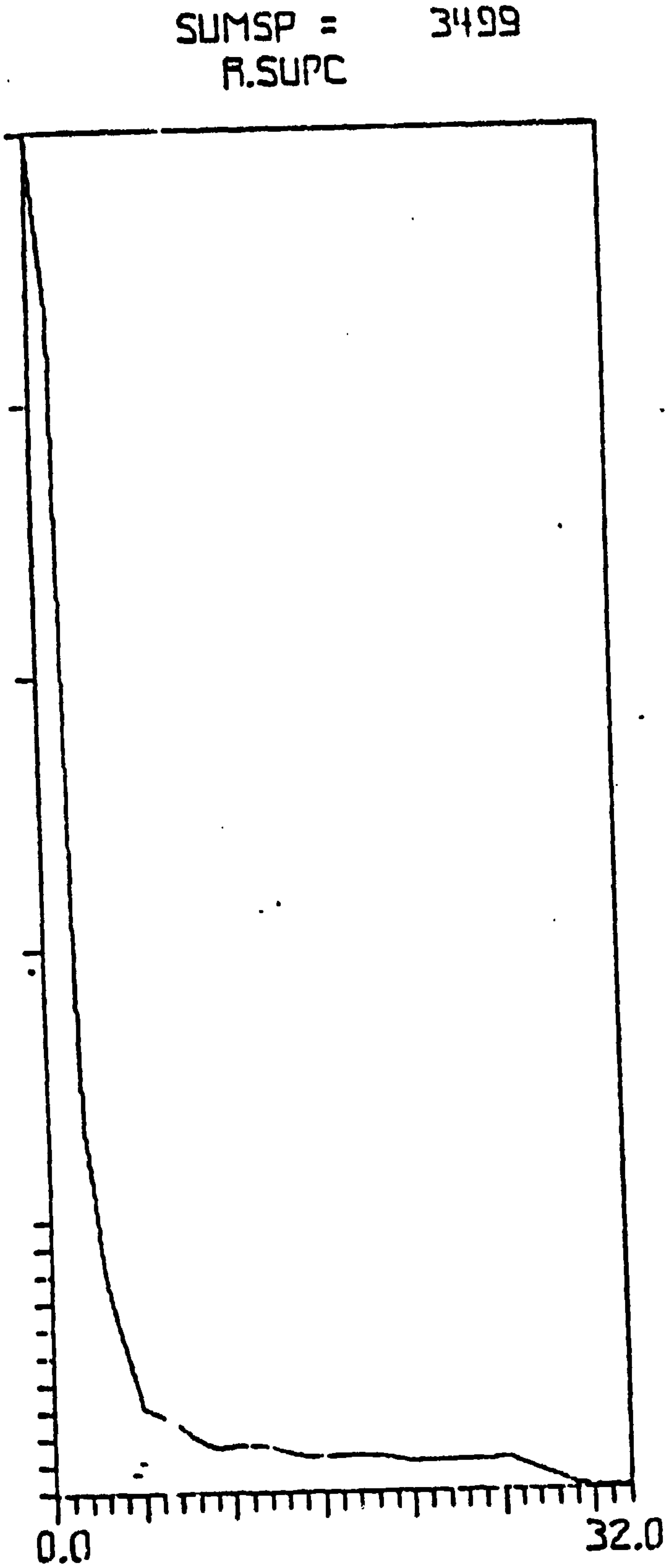
Animal G 56 V/M
Control Incorrect
40 cases



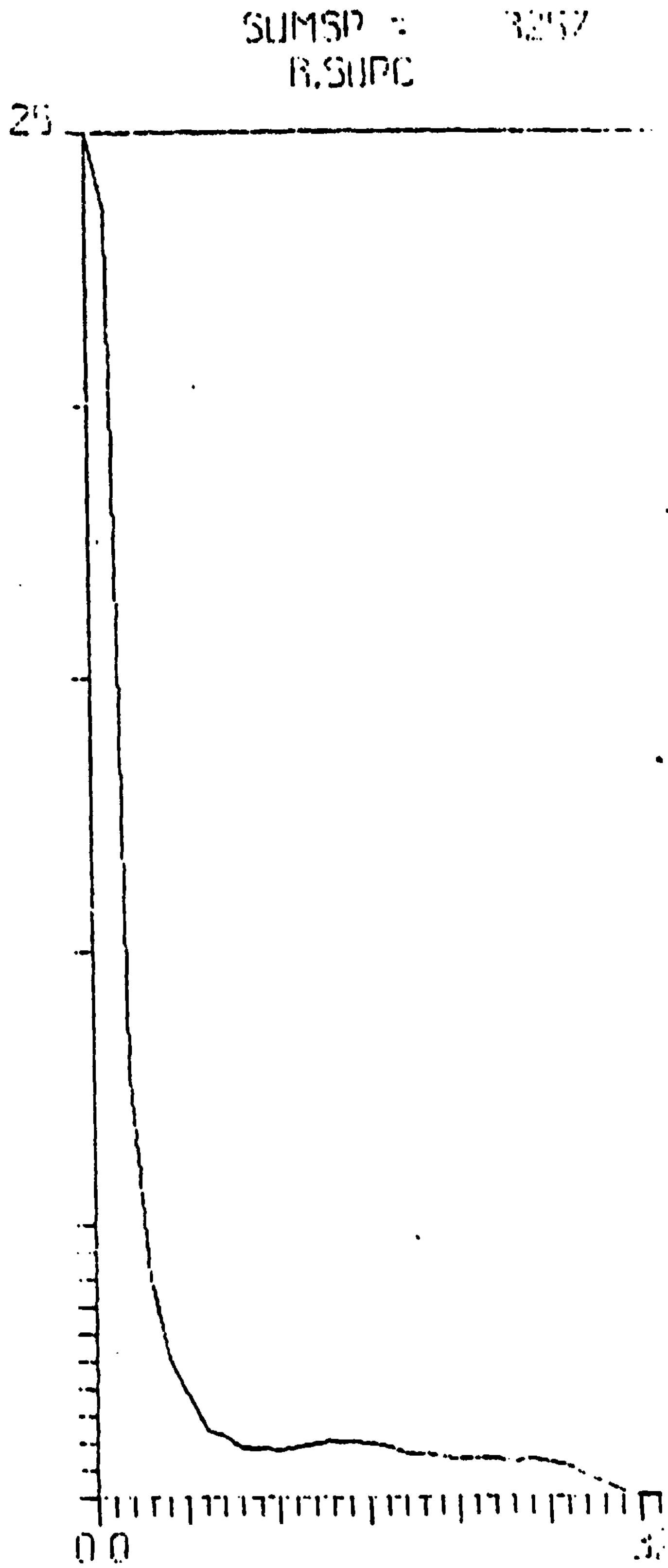
Animal G 56 V/M
MSK+60 Hz Correct
24 cases



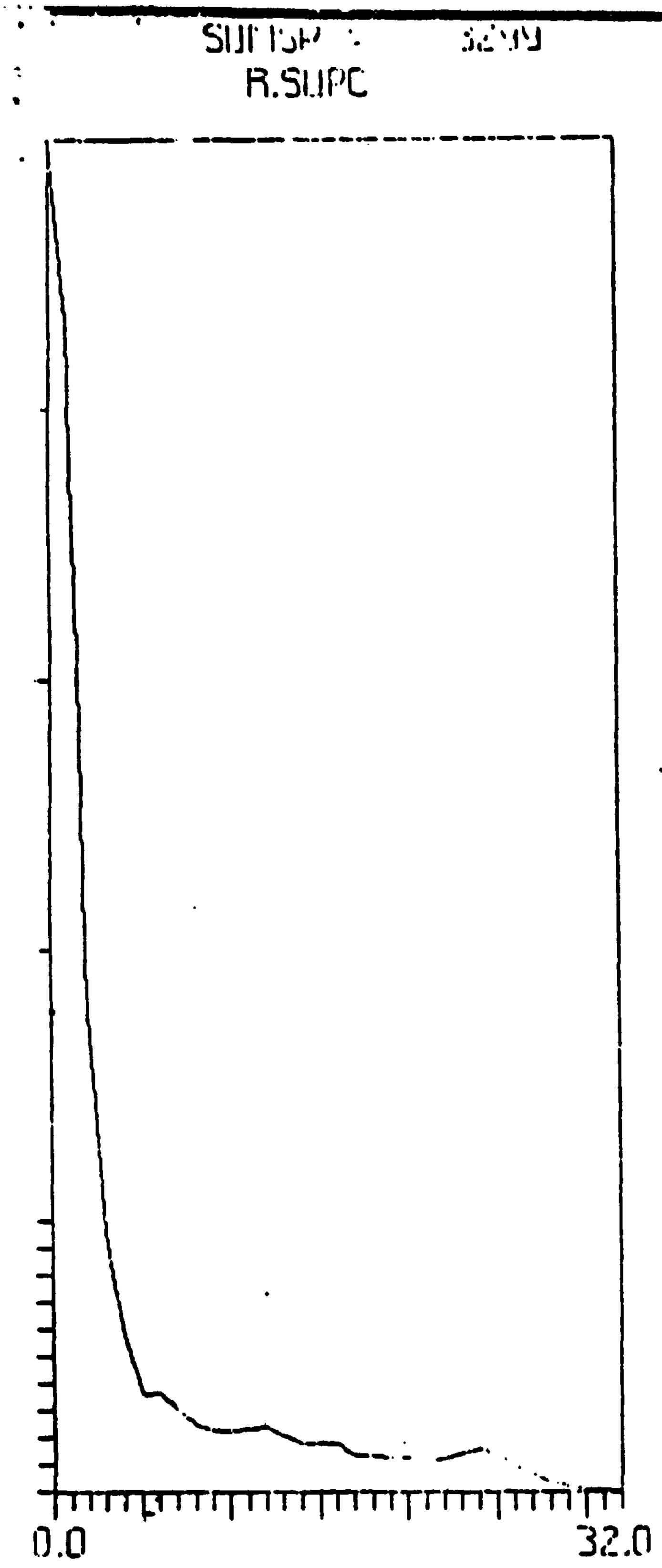
Animal G 56 V/M
MSK+60 Hz Incorrect
24 cases



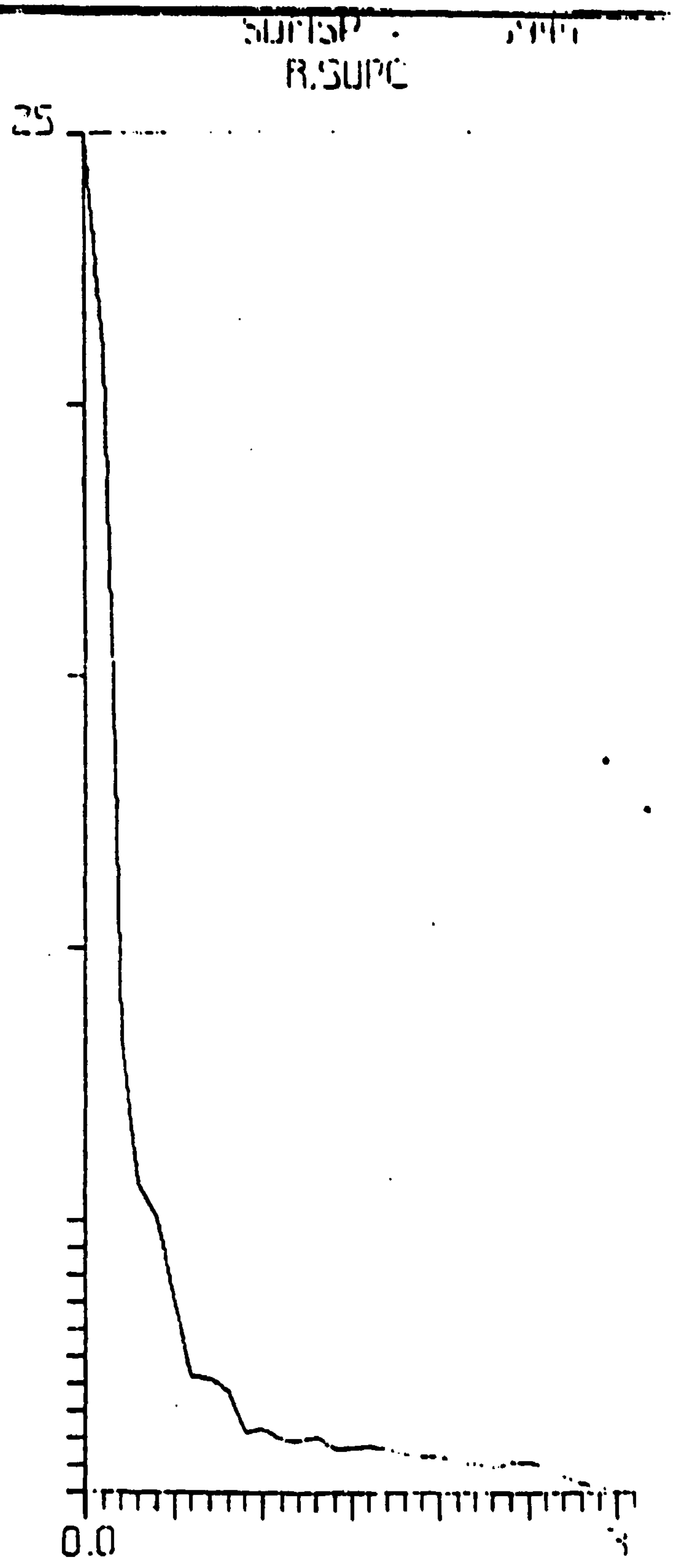
Animal G 10 V/M
Control Correct
47 cases



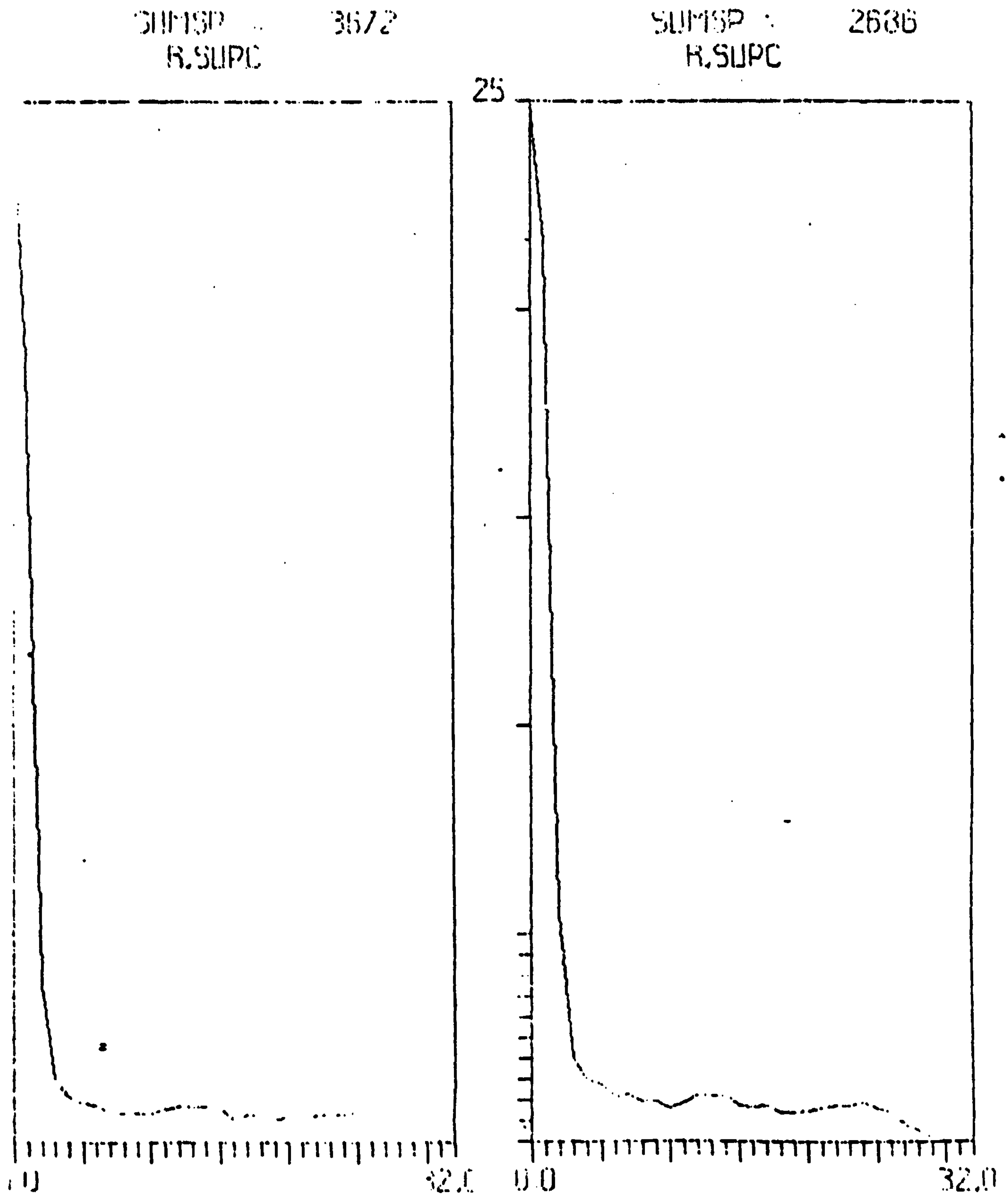
Animal G 10 V/M
Control Incorrect
47 cases



Animal G 10 V/M
76 Hz Correct
24 cases

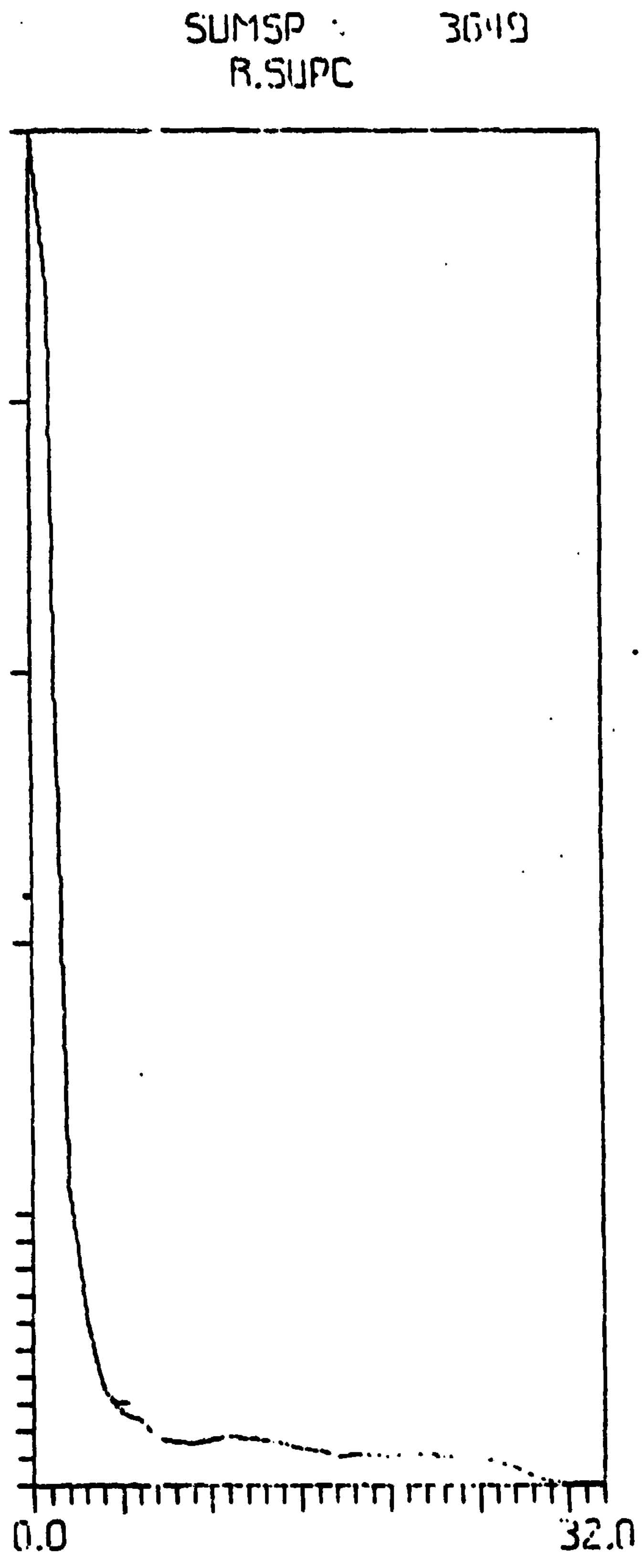


Animal G 10 V/M
76 Hz Incorrect
24 cases

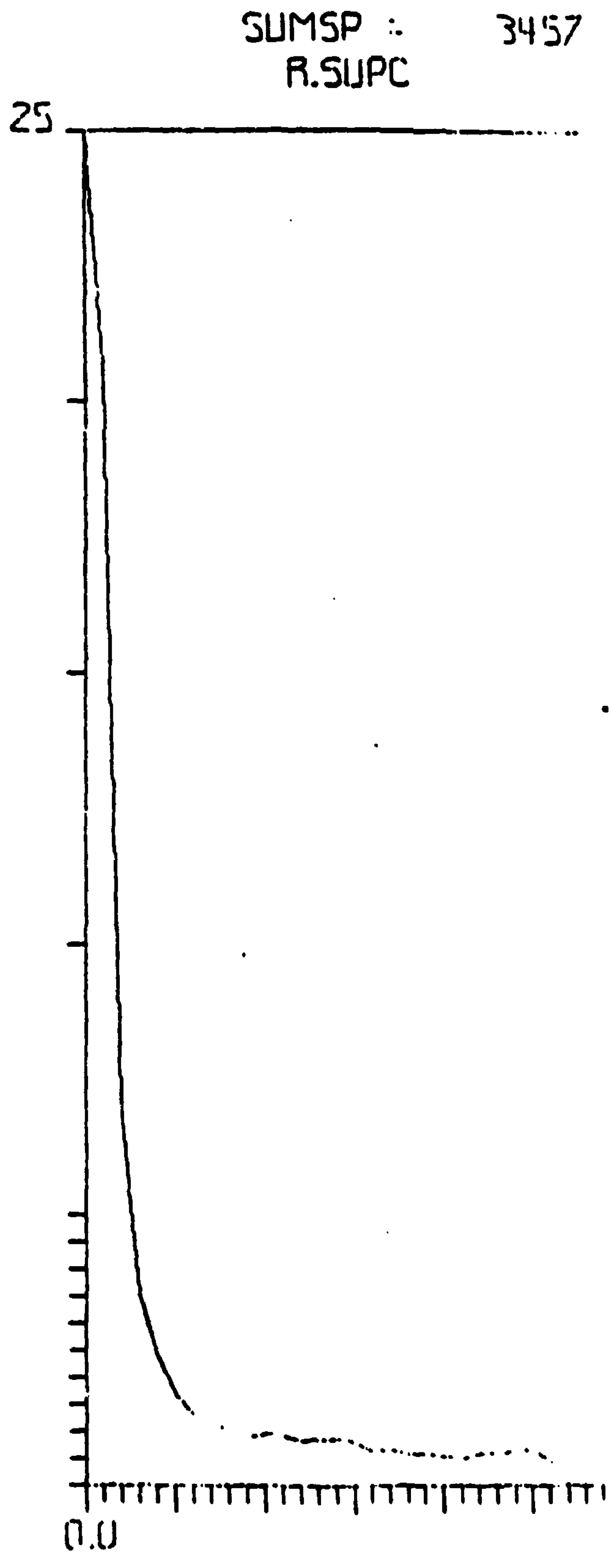


Animal G 56 V/M
76 Hz Correct
24 cases

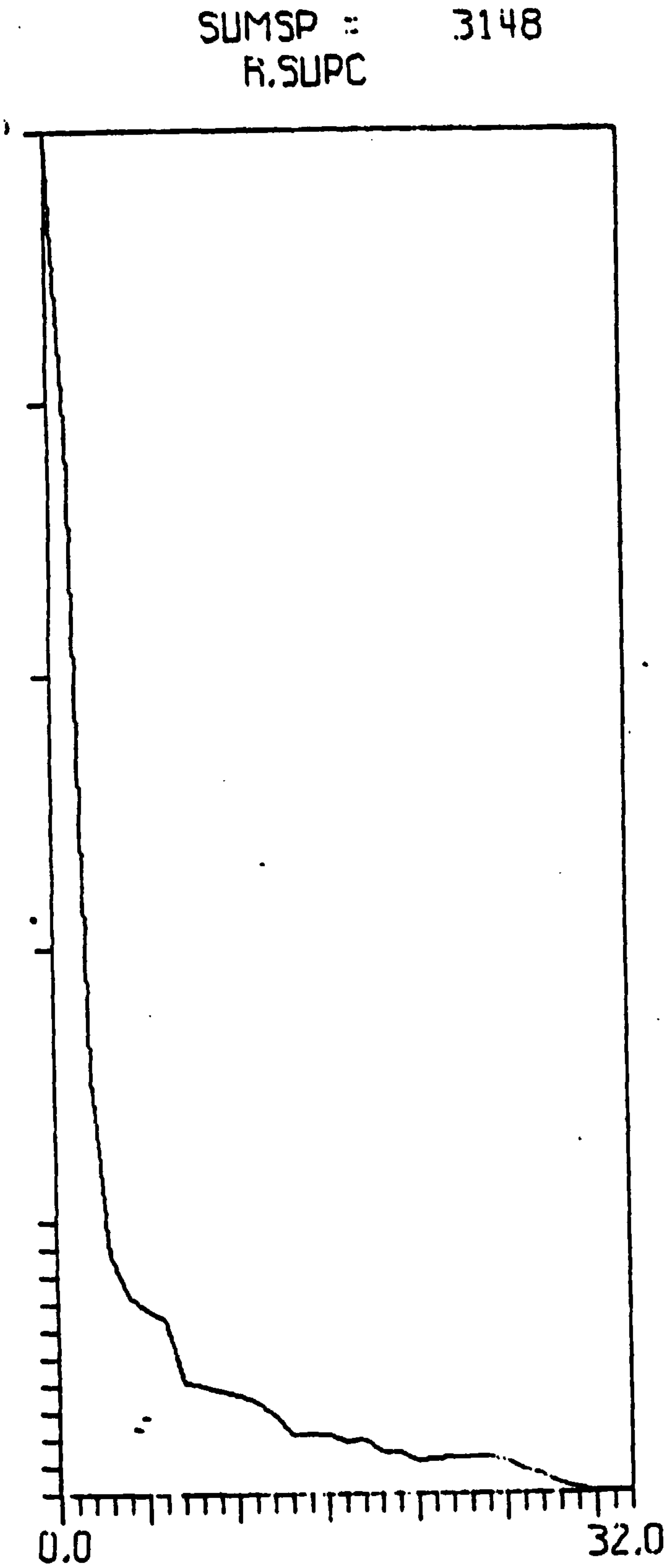
Animal G 56 V/M
76 Hz Incorrect
23 cases



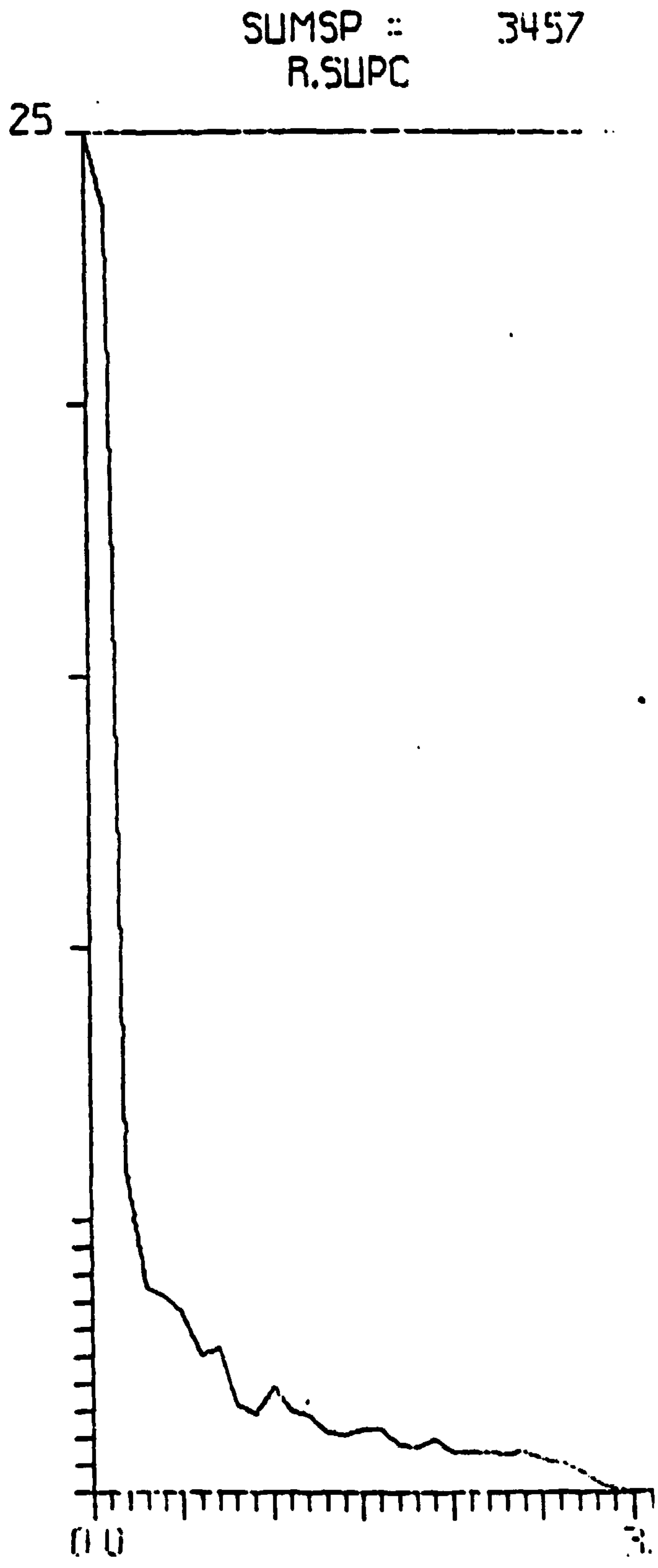
Animal G 10 V/M
MSK Correct
24 cases



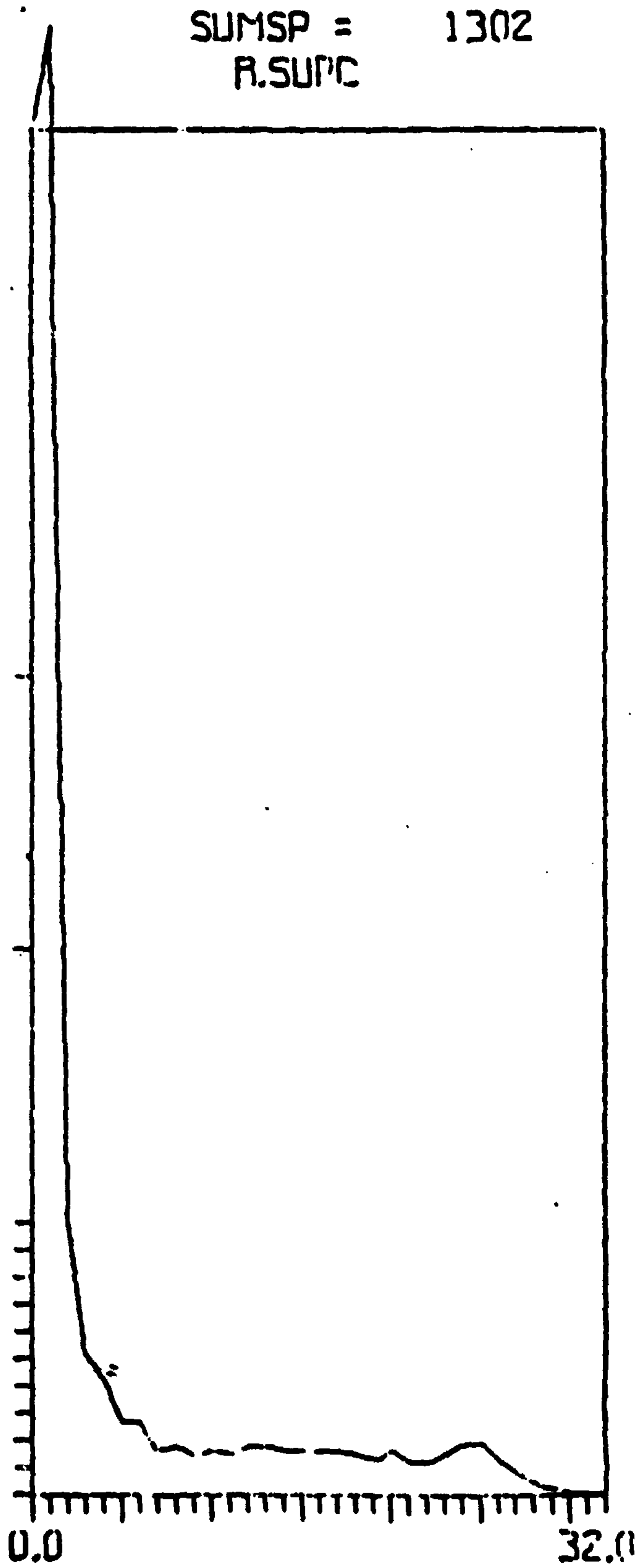
Animal G 10 V/M
MSK Incorrect
24 cases



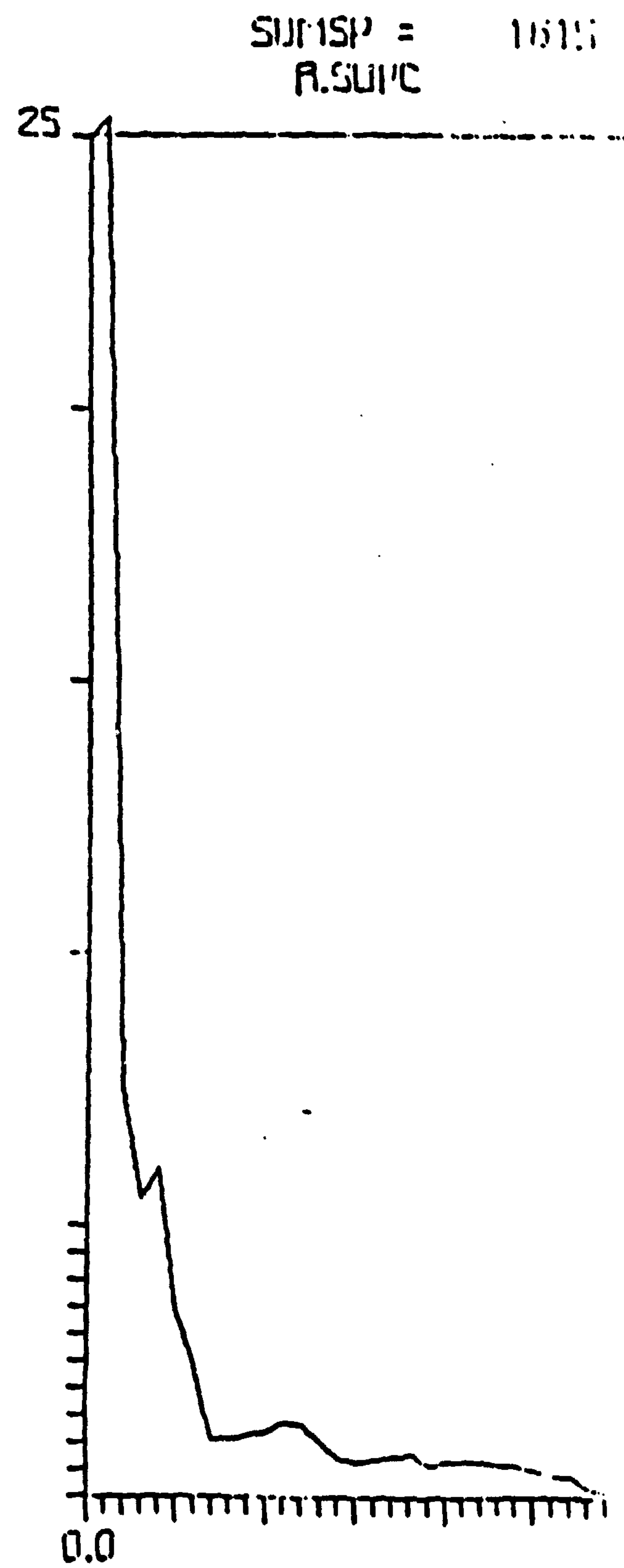
Animal G 56 V/M
MSK Correct
21 cases



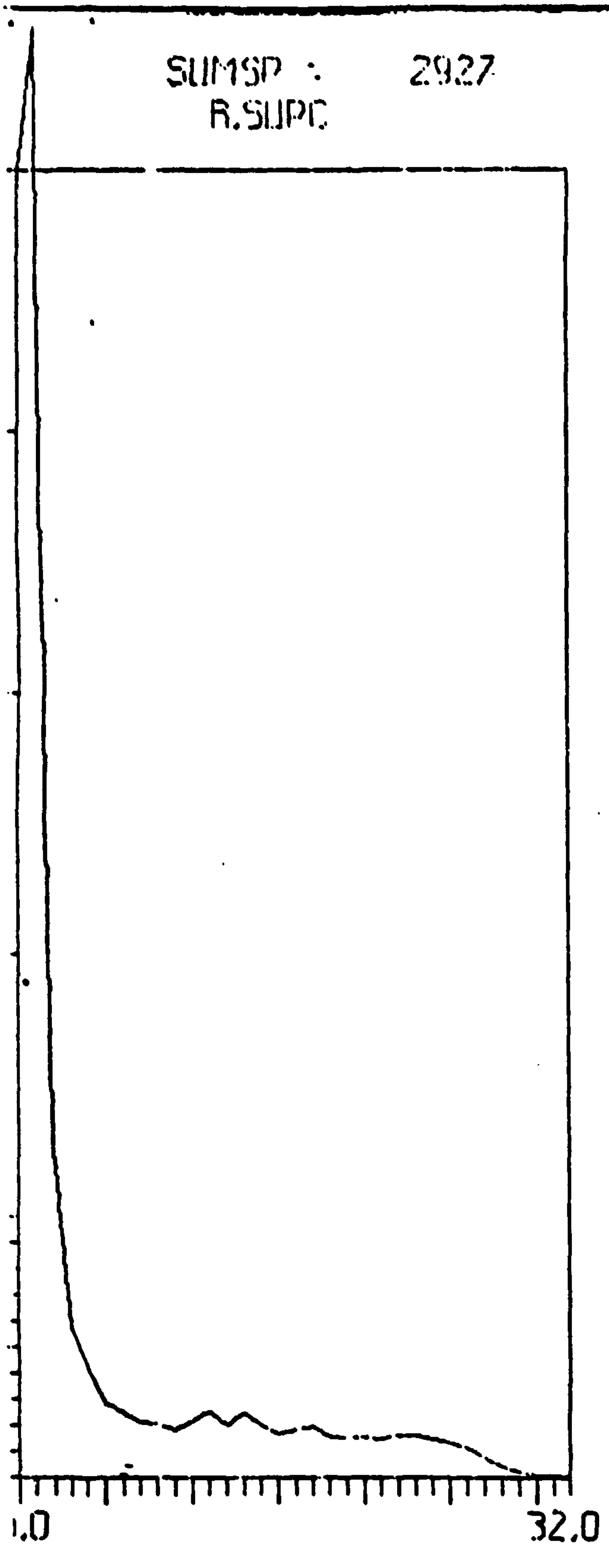
Animal G 56 V/M
MSK Incorrect
13 cases



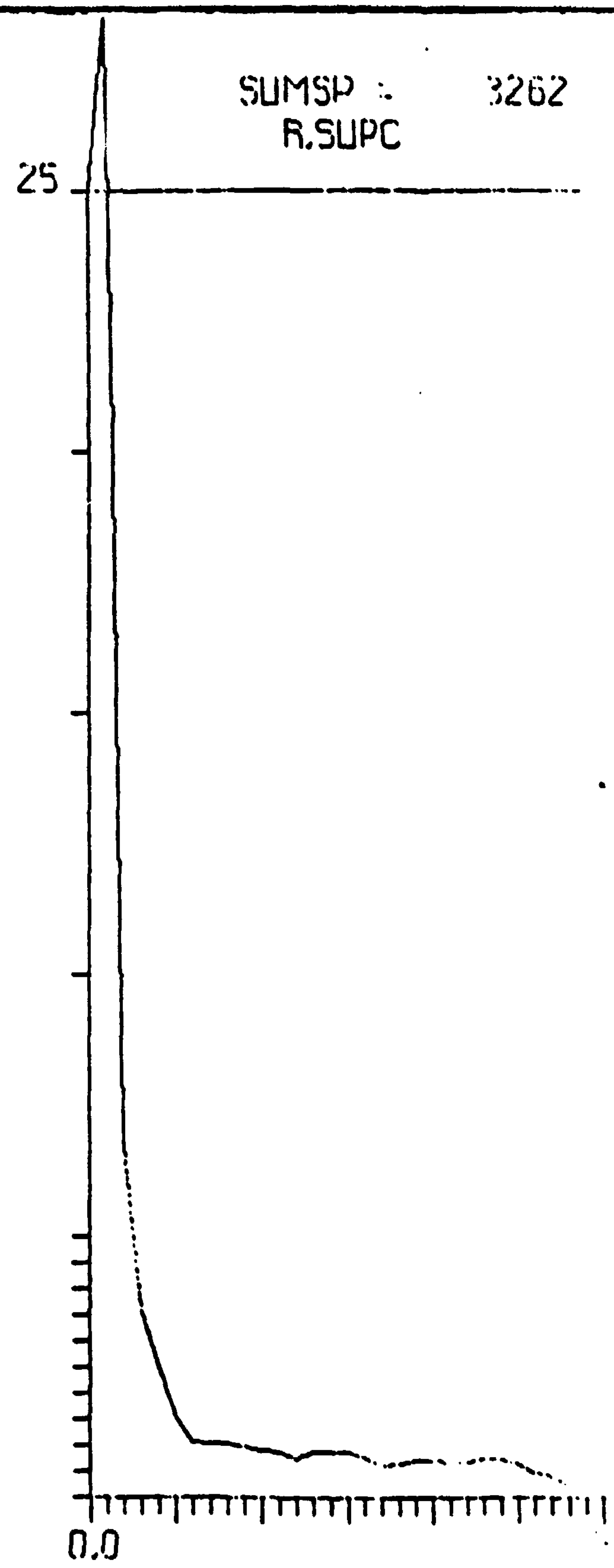
Animal G 10 V/M
MSK+60 Hz Correct
24 cases



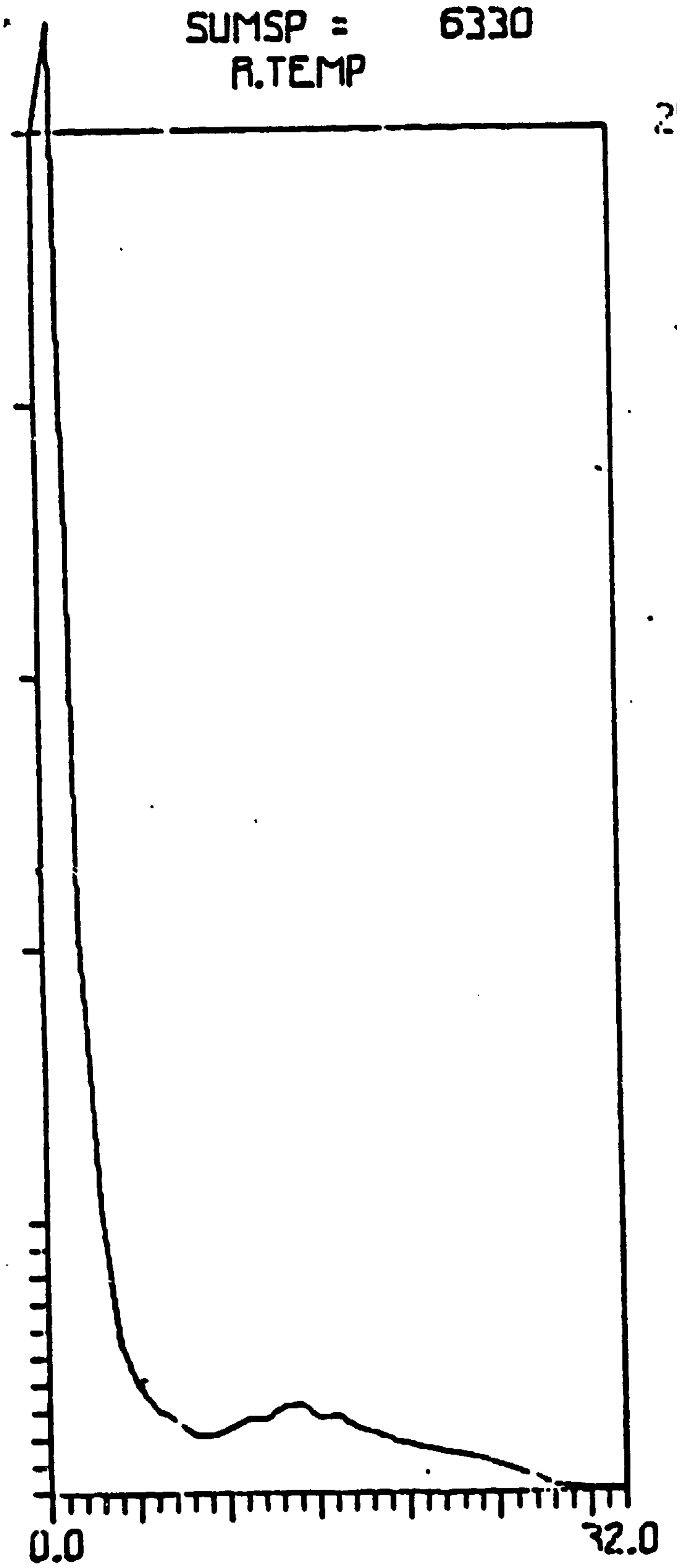
Animal G 10 V/M
MSK+60 Hz Incorrect
24 cases



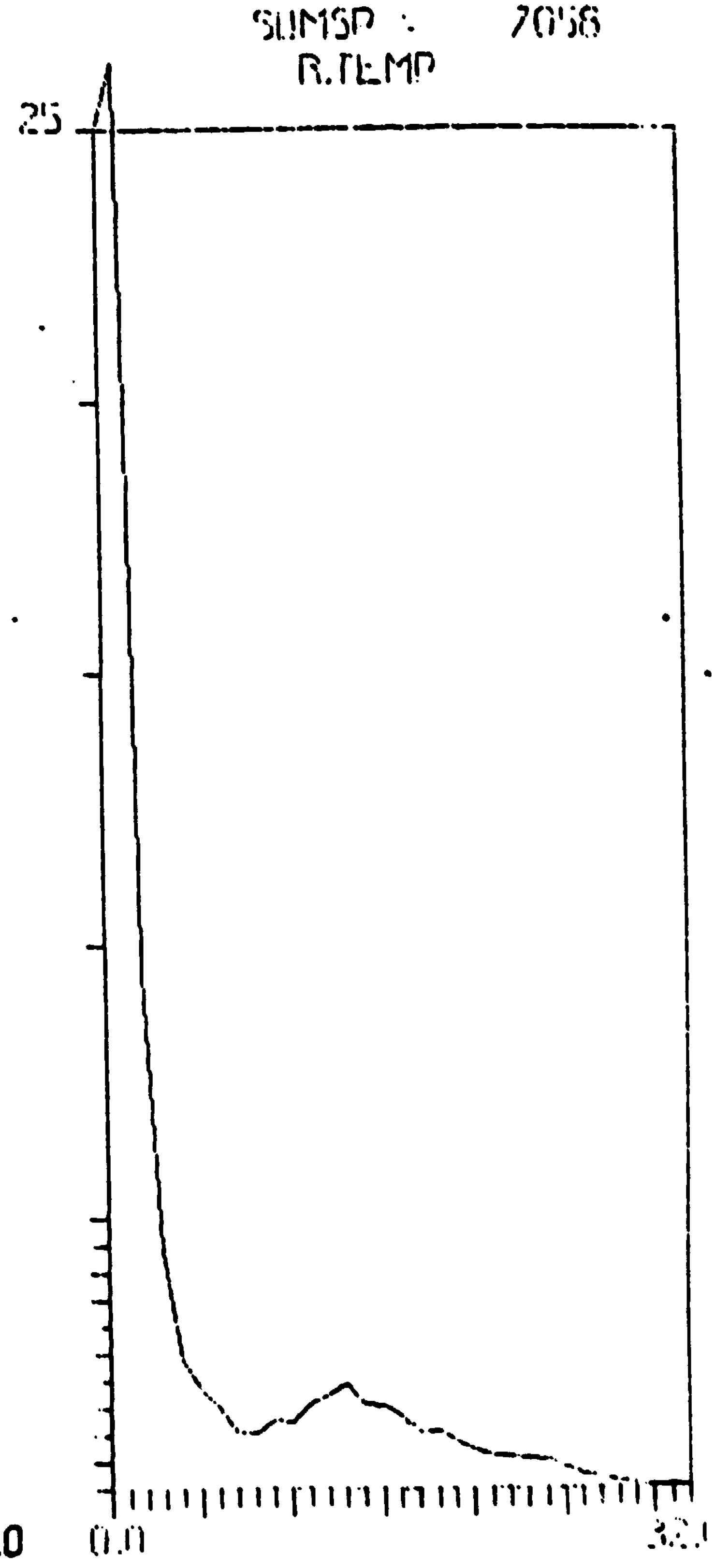
Animal G 56 V/M
MSK+60 Hz Correct
24 cases



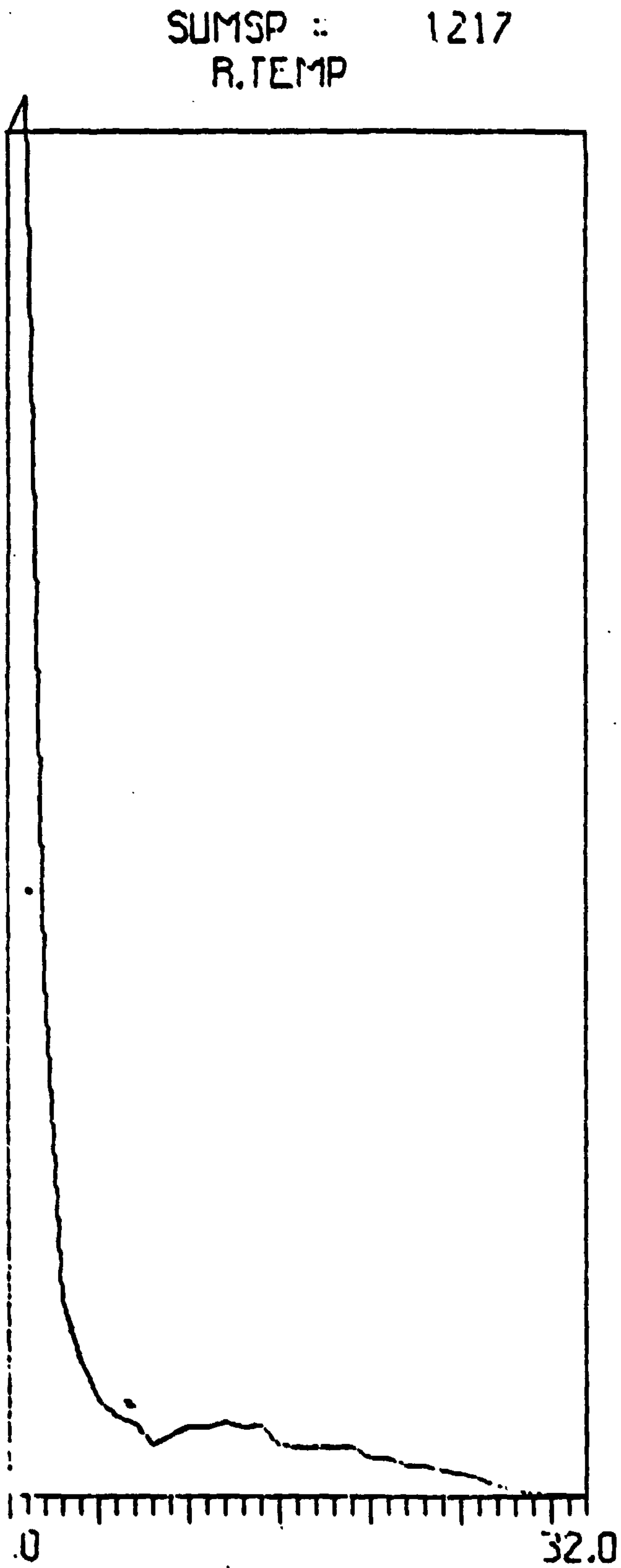
Animal G 56 V/M
MSK+60 Hz Incorrect
24 cases



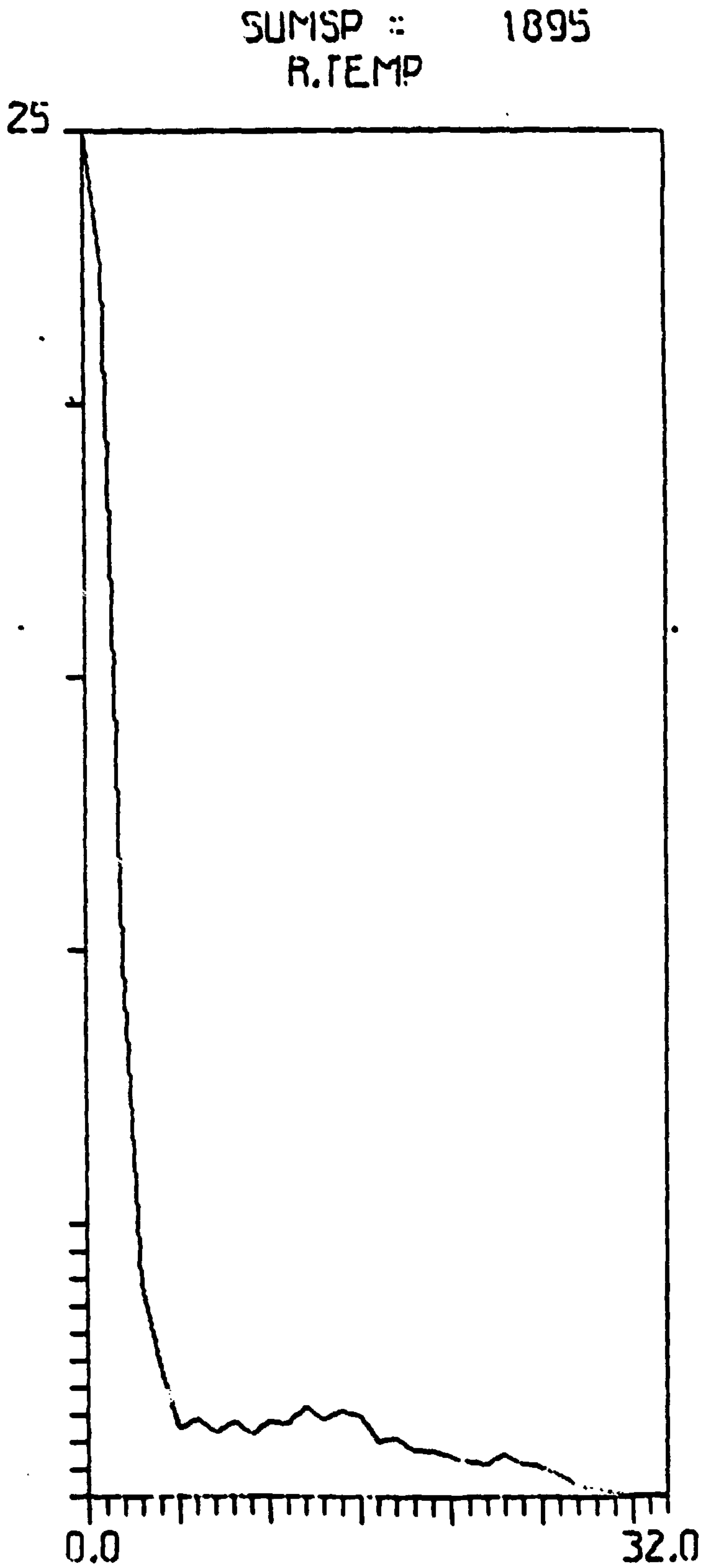
Animal G 10 V/M
Control Correct
47 cases



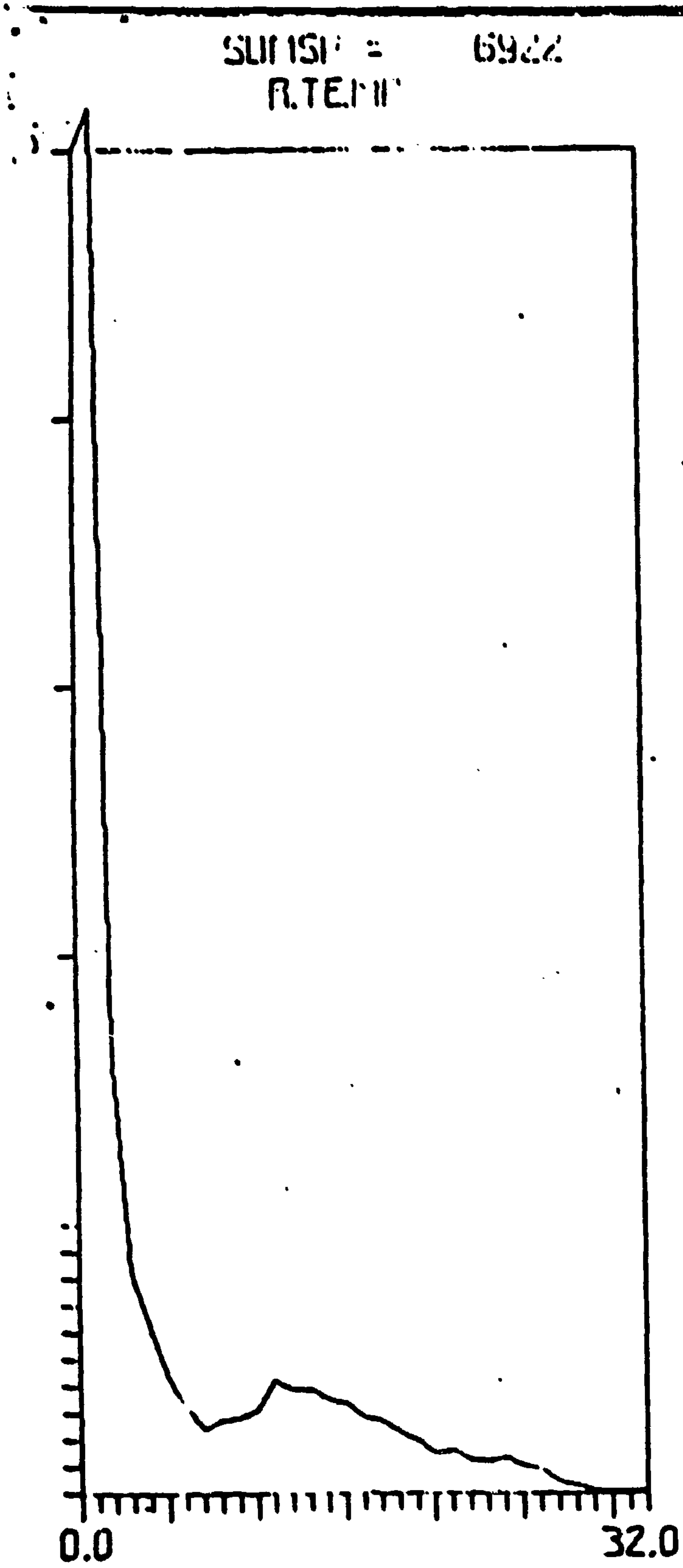
Animal G 10 V/M
Control Incorrect
47 cases



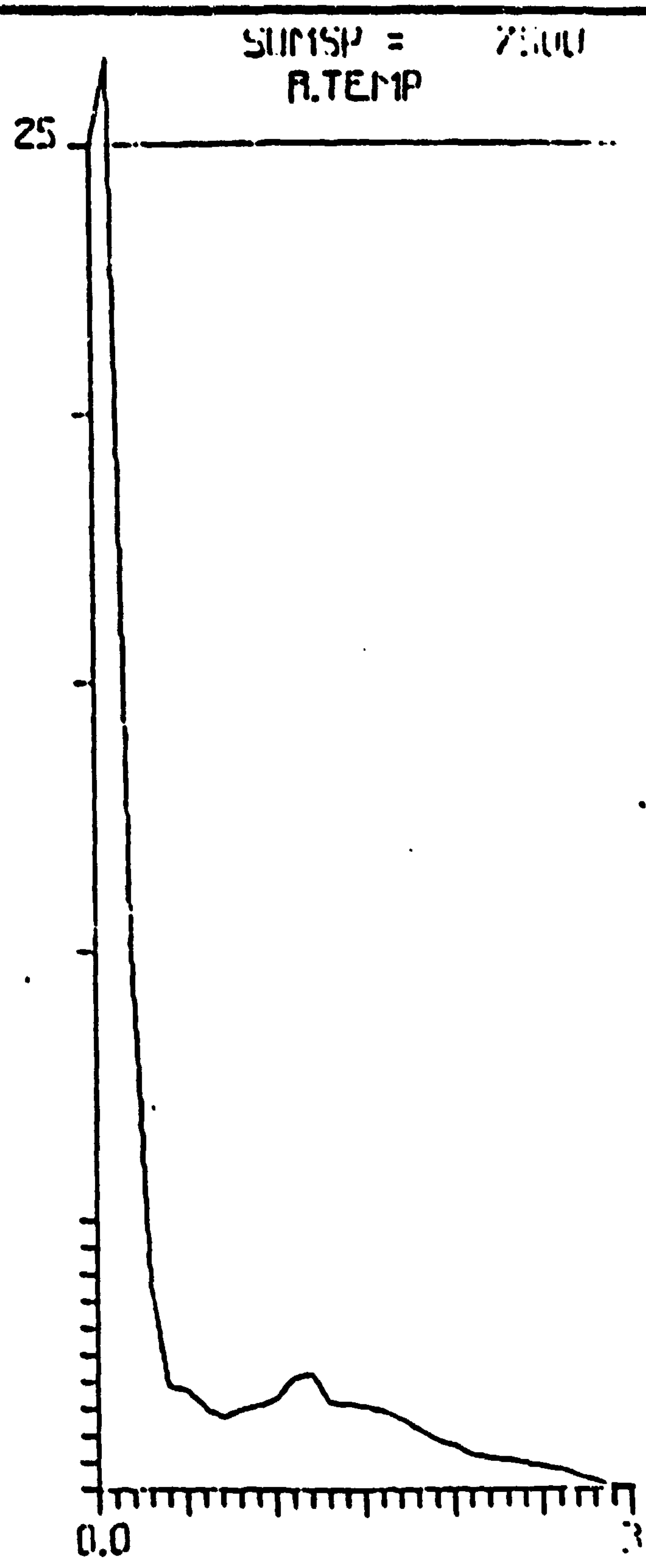
Animal G 56 V/M
Control Correct
37 cases



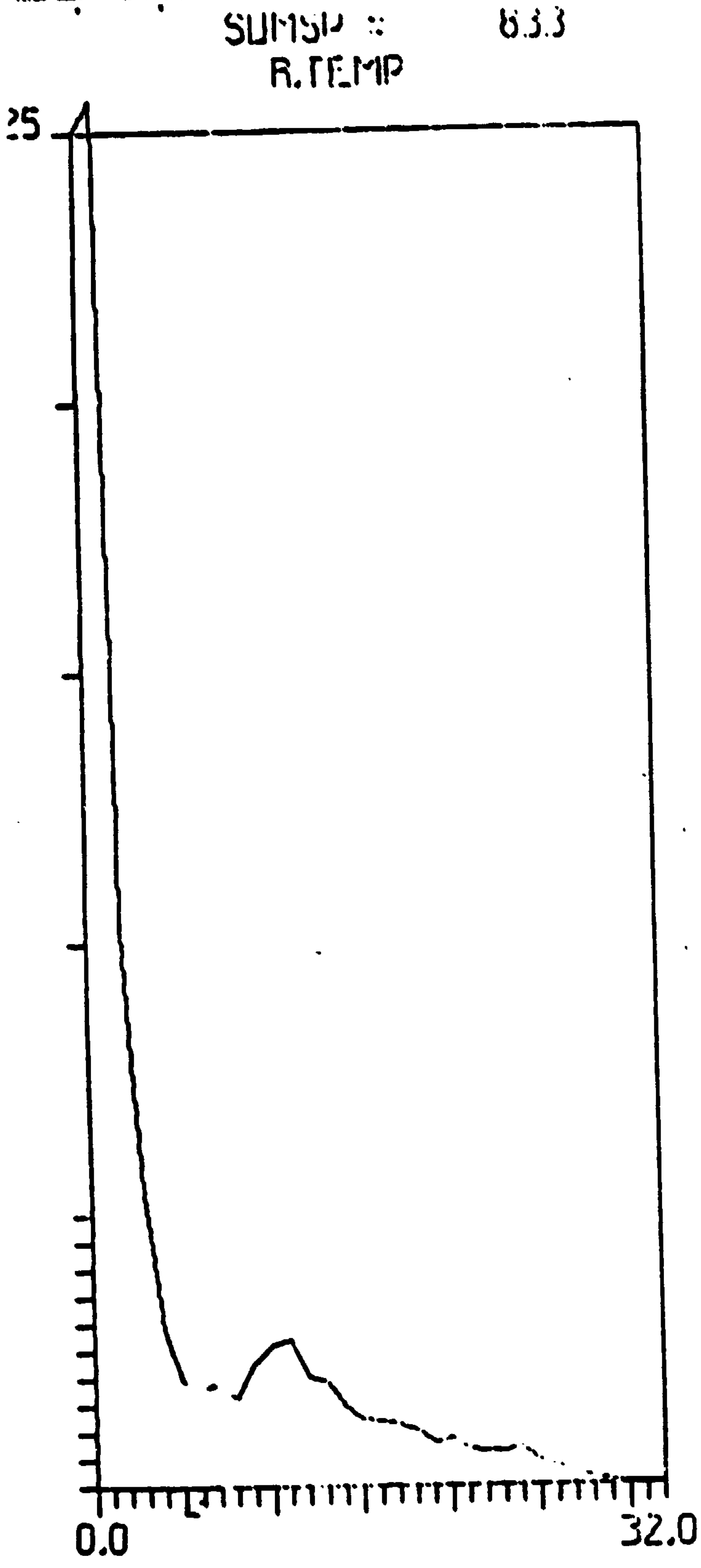
Animal G 56 V/M
Control Incorrect
40 cases



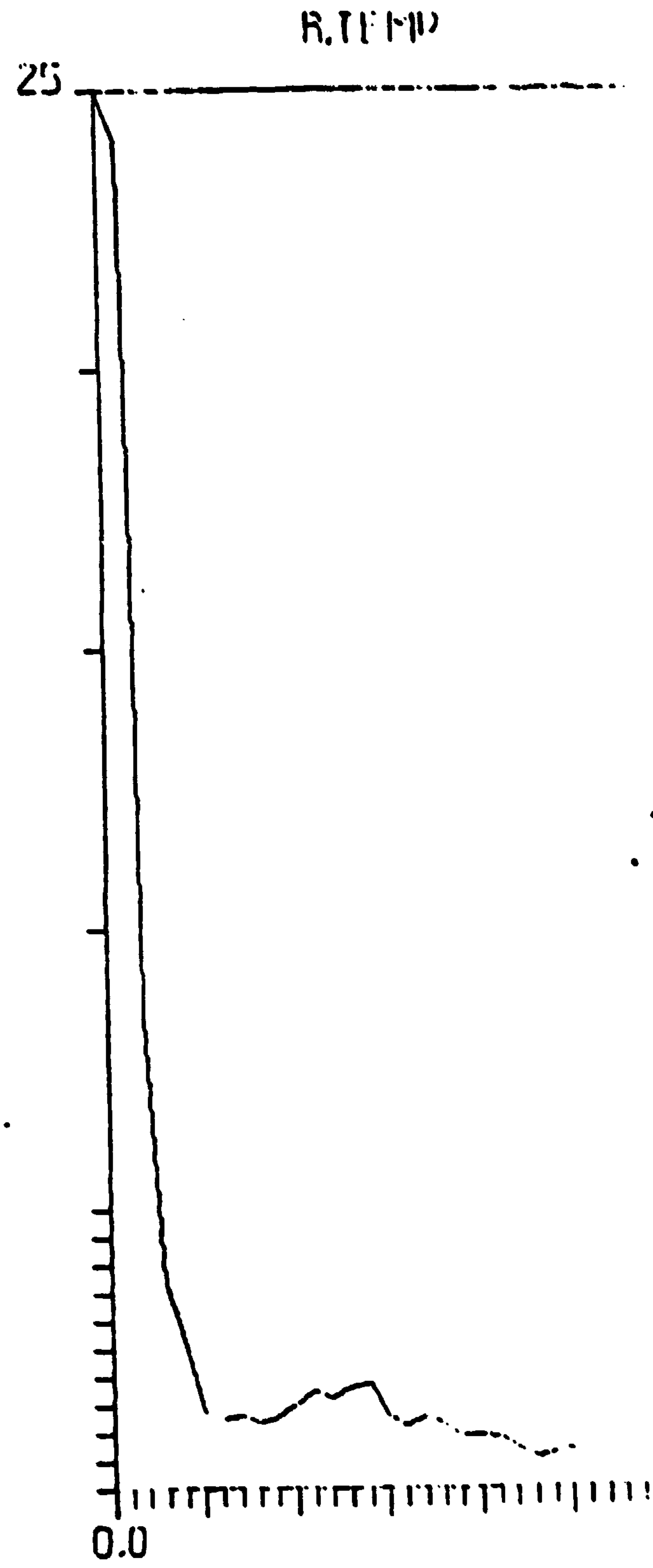
Animal G 10 V/M
7 Hz Correct
22 cases



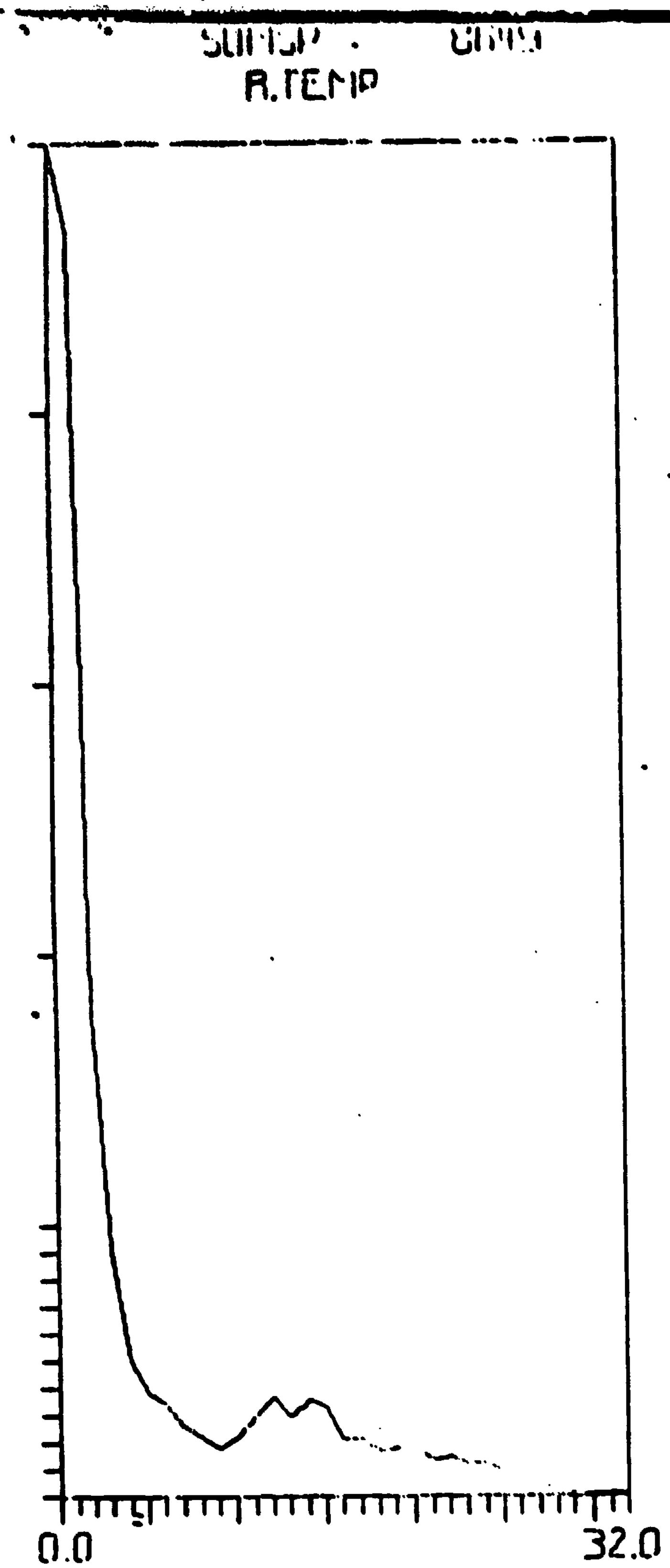
Animal G 10 V/M
7 Hz Incorrect
23 Cases



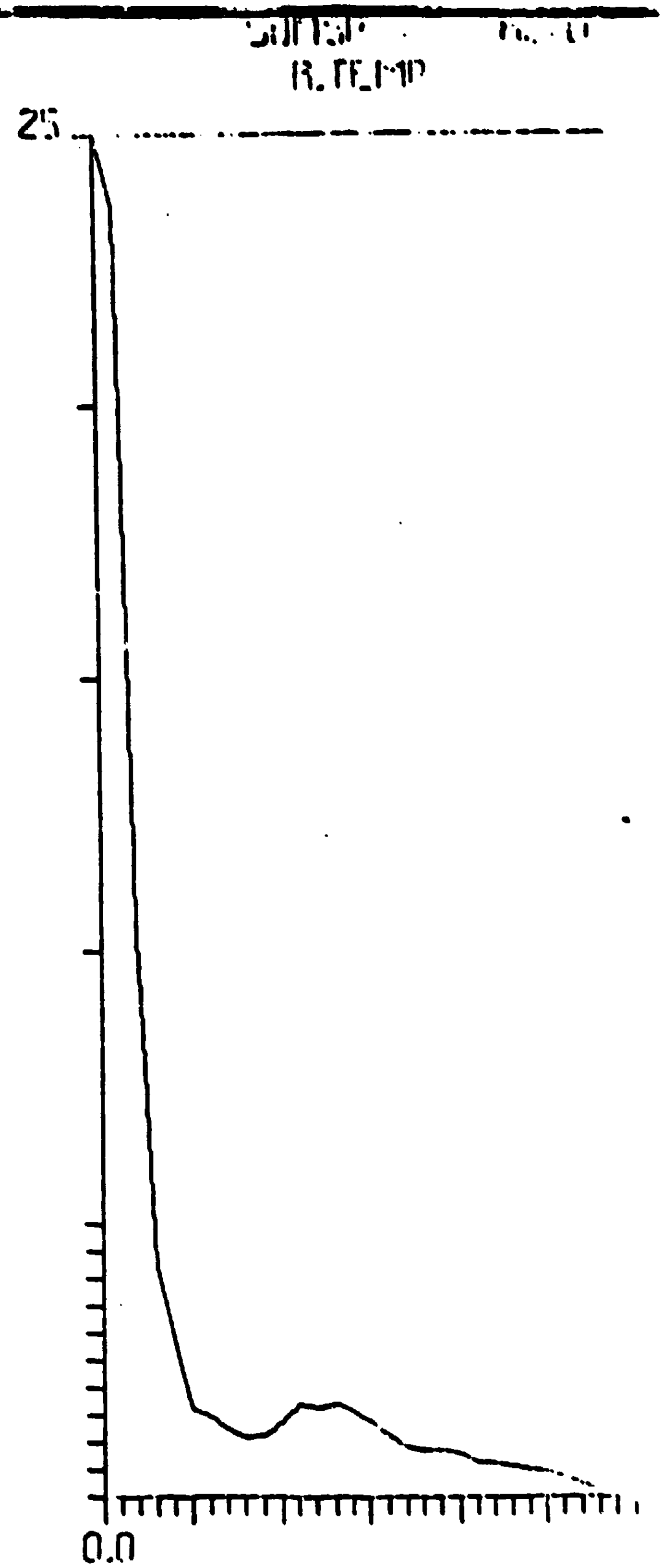
Animal G 56 V/M
7 Hz Correct
12 cases



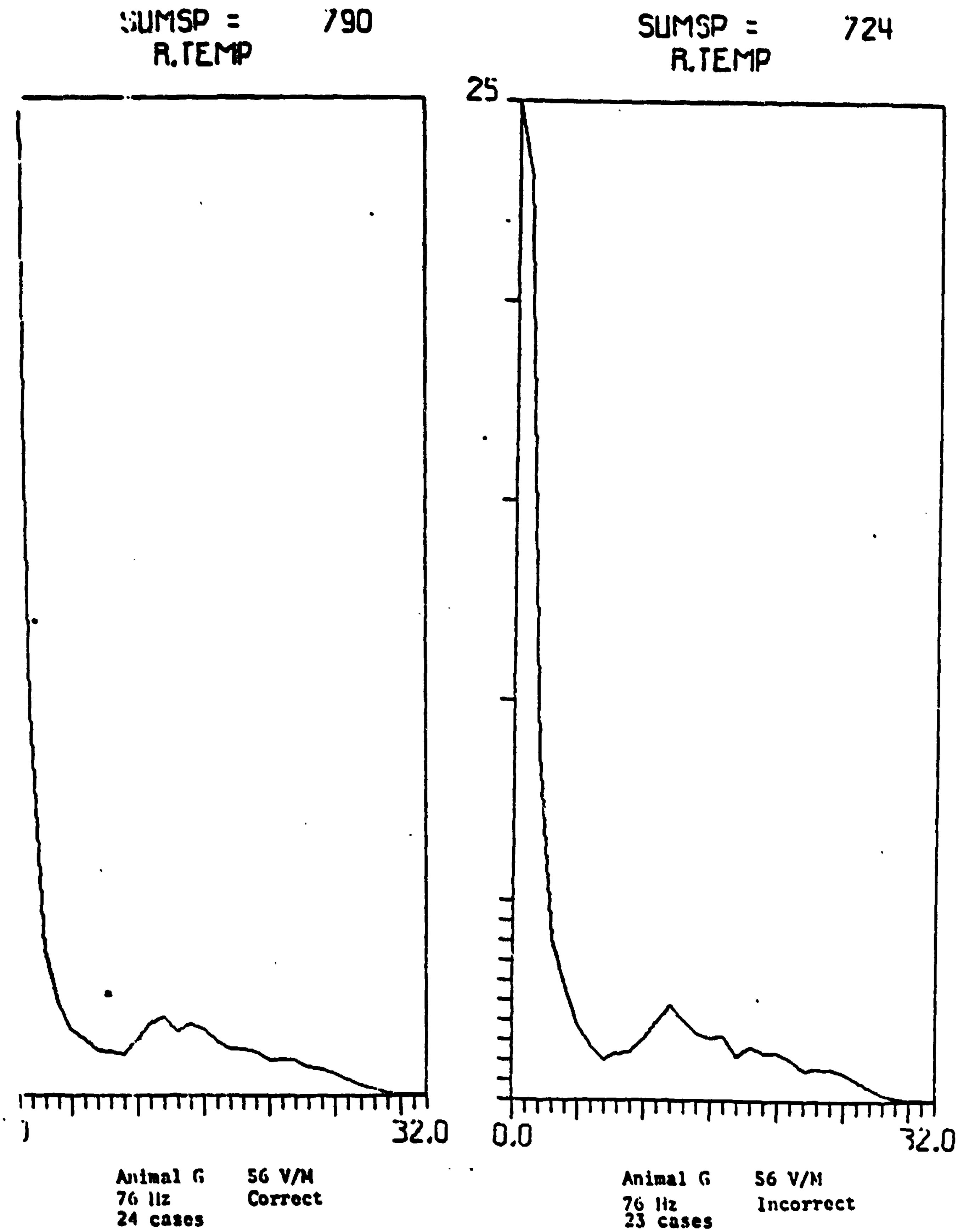
Animal G 56 V/M
7 Hz Incorrect
12 cases

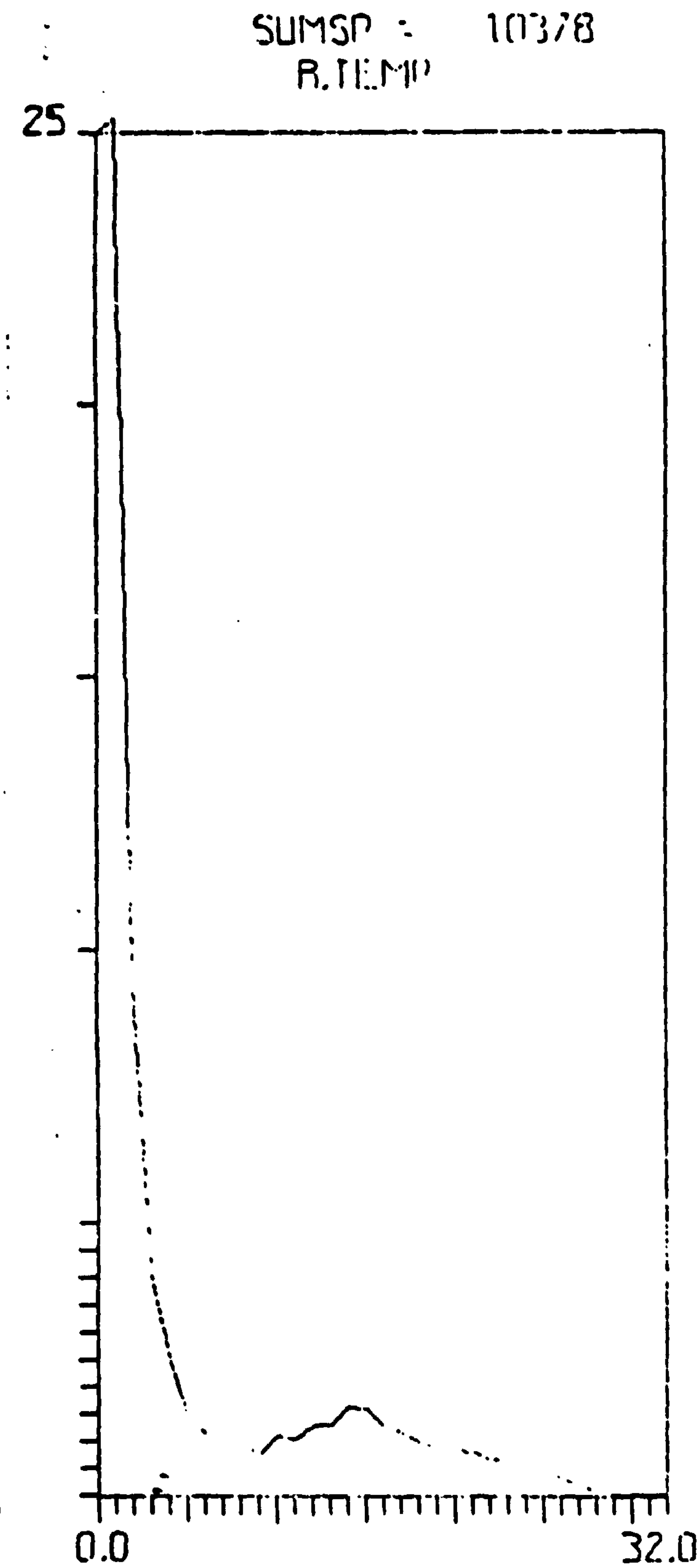


Animal G 10 V/M
76 Hz Correct
24 cases

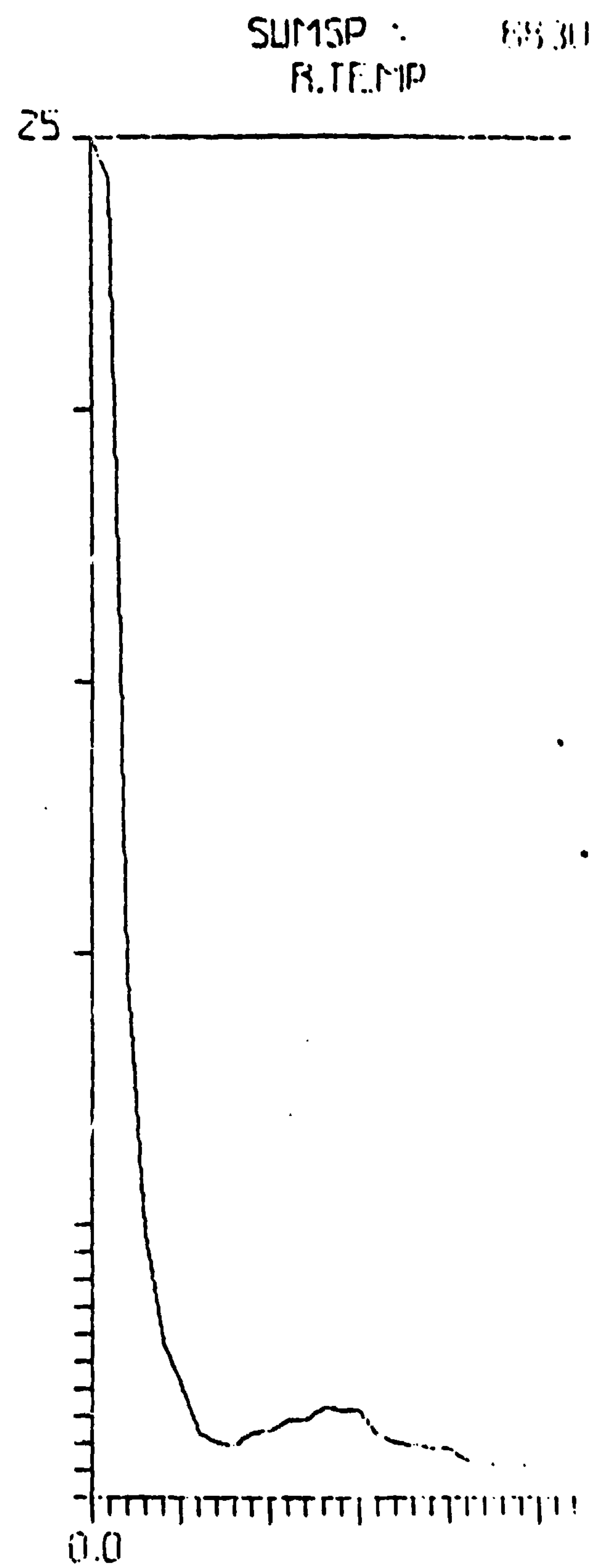


Animal G 10 V/M
76 Hz Incorrect
24 cases

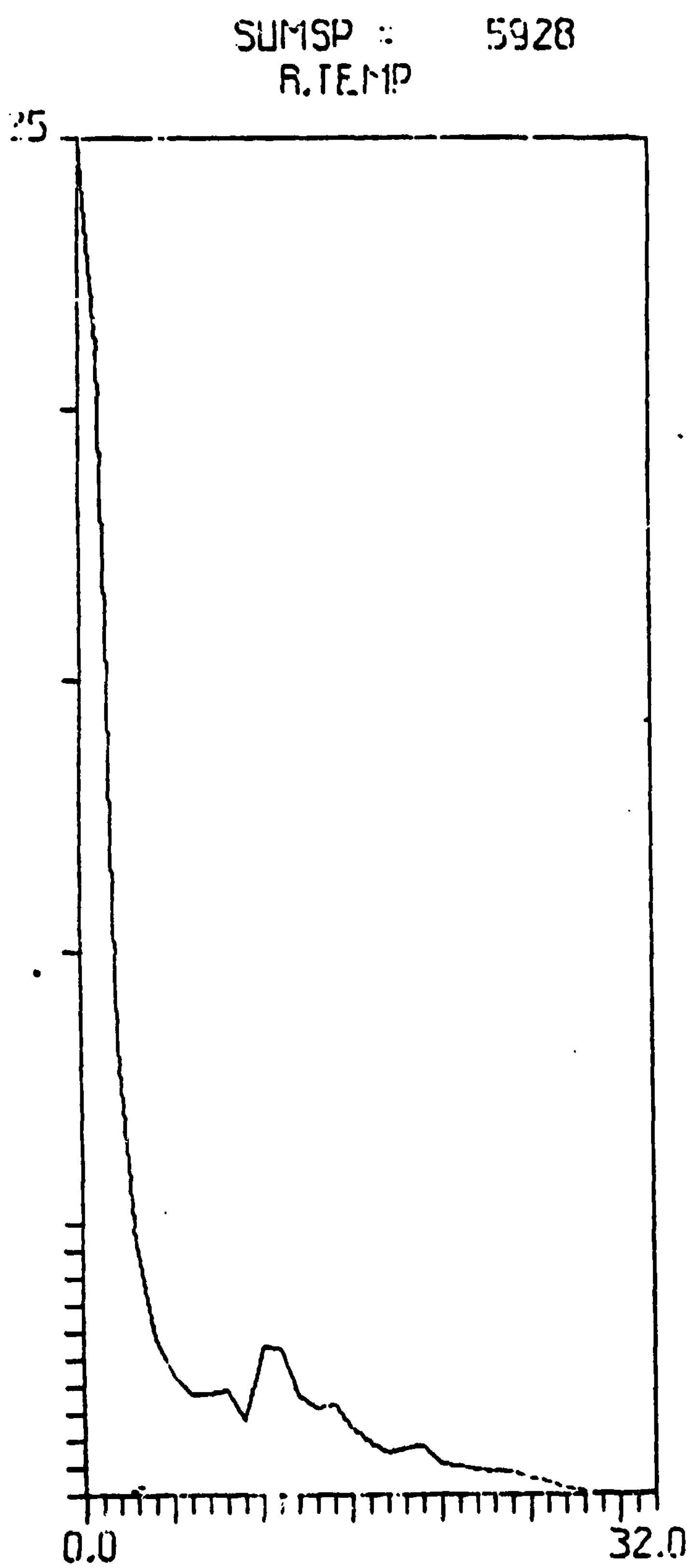

SUMSP = 790
R.TEMP
32.0
Animal G 56 V/M
76 Hz Correct
24 cases
SUMSP = 724
R.TEMP
25
0.0
32.0
Animal G 56 V/M
76 Hz Incorrect
23 cases



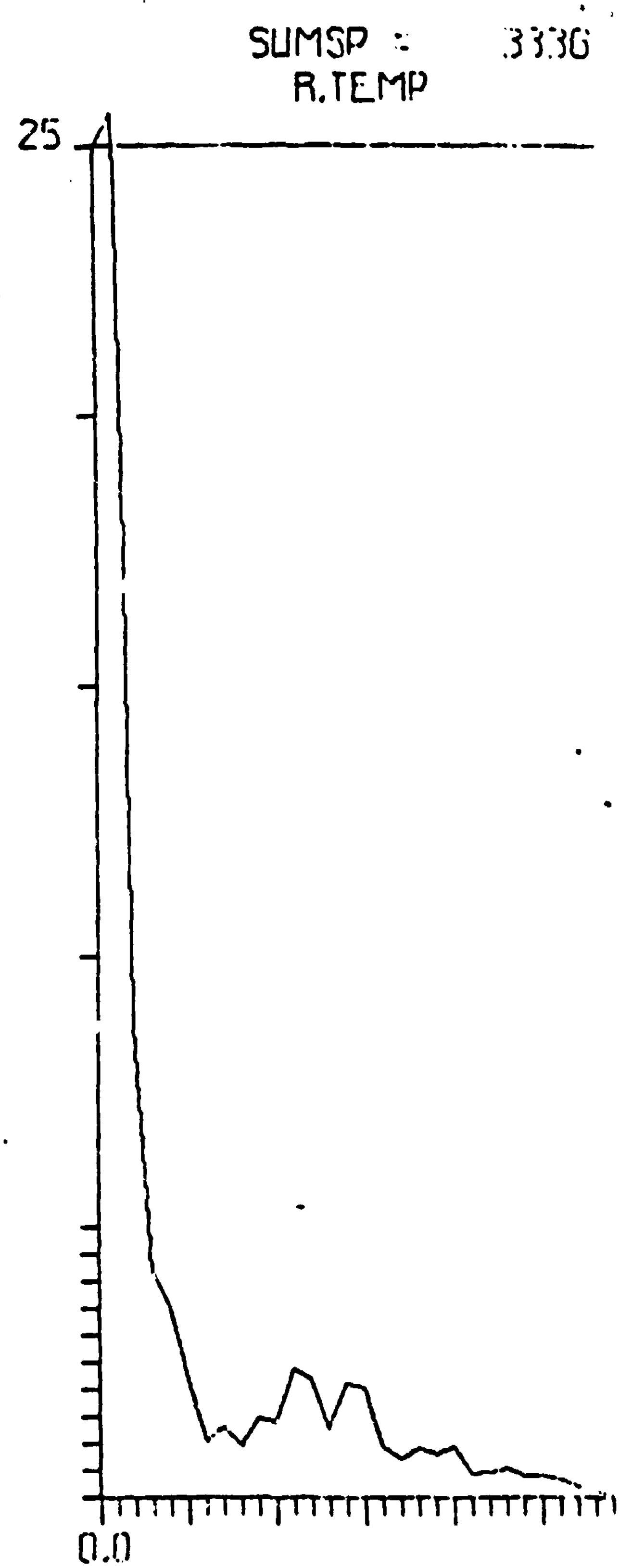
Animal G 10 V/M
MSK Correct
24 cases



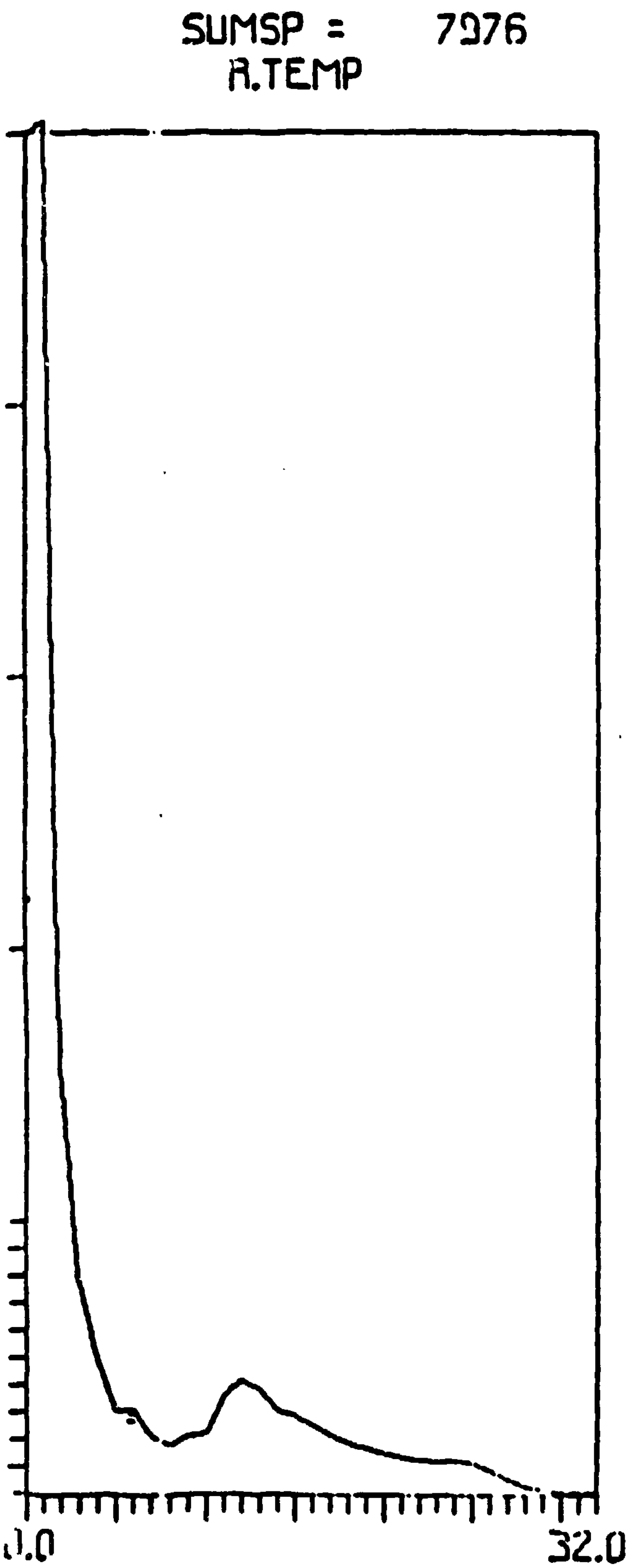
Animal G 10 V/M
MSK Incorrect
24 cases



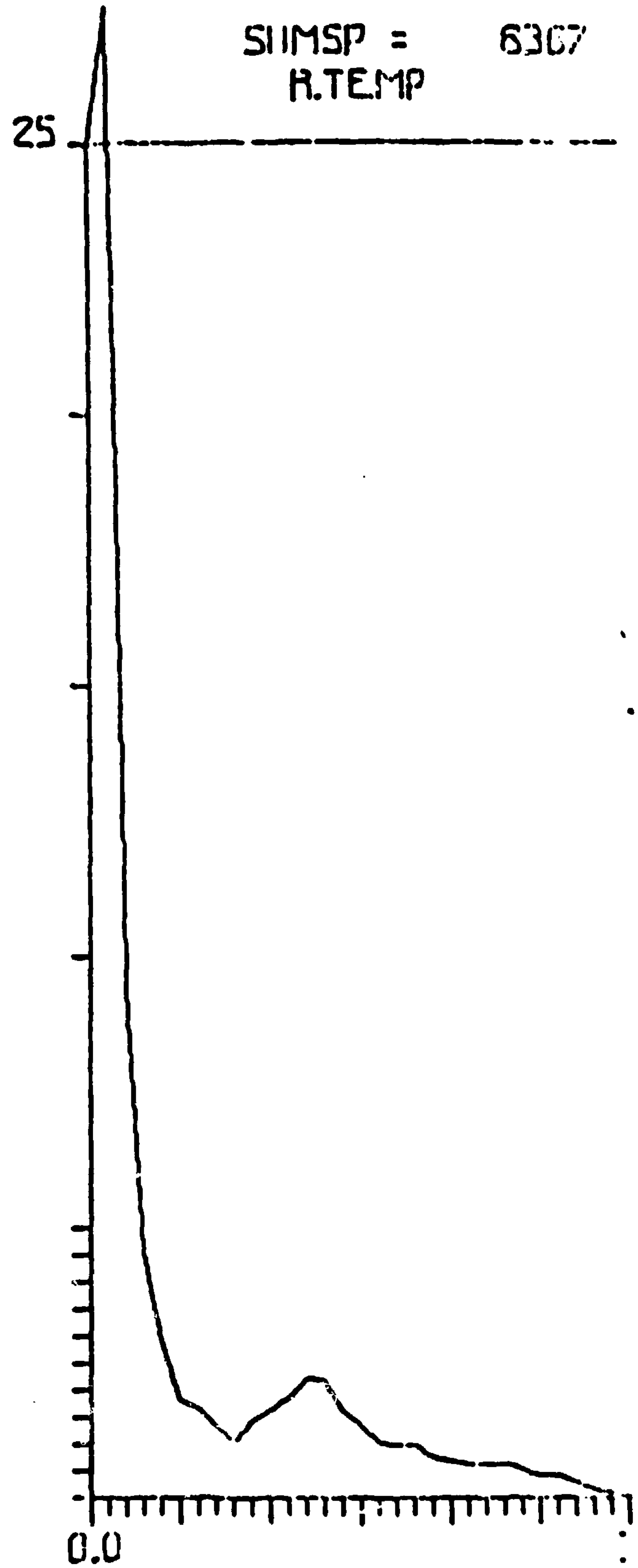
Animal G 56 V/M
MSK Correct
21 cases



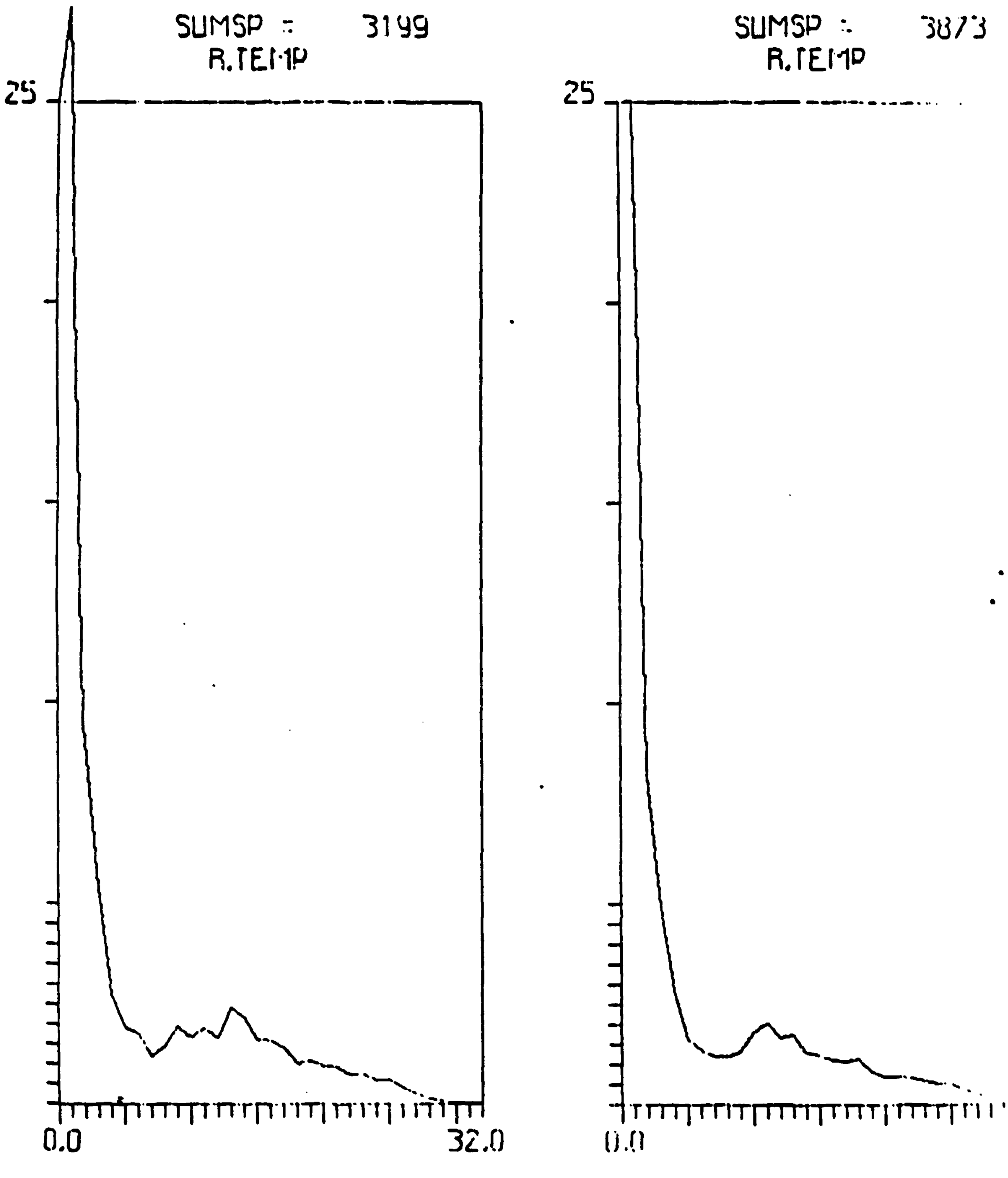
Animal G 56 V/M
MSK Incorrect
13 cases



Animal G 10 V/M
MSK+60 Hz Correct
24 cases



Animal G 10 V/M
MSK+60 Hz Incorrect
24 cases



Animal G 56 V/M
MSK+60 Hz Correct
24 cases

Animal G 56 V/M
MSK+60 Hz Incorrect
24 cases

APPENDIX II.

ELECTROMAGNETIC FIELD MEASUREMENTS IN SUPPORT

OF PRIMATE BEHAVIORAL AND EEG STUDIES

J.R. GAUGER and N.C. ROBERTSON

APPENDIX III.

REPRINTS OF PUBLISHED MATERIAL

1. GAVALAS-MEDICI, R., and S. R. DAY-MAGDALENO. Extremely low frequency, weak electric fields affect schedule-controlled behaviour in monkeys. Nature, Vol. 261, No. 5557, pp.256-259, 1978.

2. GAVALAS-MEDICI, R. Effects of weak electric fields on behavior and EEG of laboratory animals. Neurosci. Res. Prog. Bull. Vol. 15, No. 1, pp. 27-36, 1977.

3. GAVALAS-MEDICI, R., and Z. M. SAGAN. Behavioral assays of possible weak ELF effects: comments and recommendations. Appendix B, Biologic Effects of Electric and Magnetic Fields Associated with Proposed Project Seafarer. Report of Committee on Biosphere Effects of Extremely-Low-Frequency Radiation, Division of Medical Sciences, Assembly of Life Sciences, National Research Council, National Academy of Sciences, 1977.

4. GAVALAS-MEDICI, R., and S. R. DAY. Effects of weak ELF electric fields on schedule-controlled behavior of monkeys. In: Selected papers of the USNC/URSI Annual Meeting on Biological Effects of Electromagnetic Waves, Boulder, Colorado, Oct. 20-23, 1975. DHEW Publication FDA 77-8010.

5. BAWIN, S.M., and W. R. ADEY. Sensitivity of calcium binding in cerebral tissue to weak environmental electric fields oscillating at low frequency. Proc. Nat. Acad. Sci. USA, Vol. 73, No. 6, pp. 1999-2003, 1976