Title

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Author

Will, Bruno E.

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Bruno E. Will, Mark R. Rosenzweig, and Edward L. Bennett

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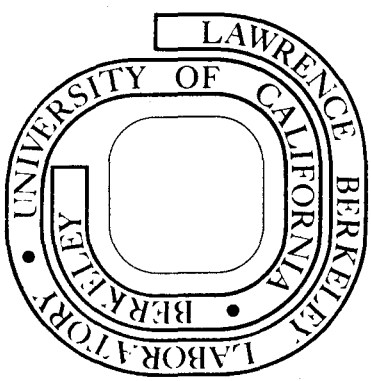

DISCLAIMER

Effects of Differential Environments on Recovery from Neonatal Brain Lesions, Measured by Problem-Solving Scores and Brain Dimensions

Bruno E. Will

Laboratoire de Psychophysiologie

Université Louis Pasteur

Strasbourg, France

Mark R. Rosenzweig

Department of Psychology

University of California, Berkeley

Edward L. Bennett

Laboratory of Chemical Biodynamics

Lawrence Berkeley Laboratory

Berkeley, California

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Abstract

To study effects of differential experience on recovery from brain lesions and on gross anatomy of the brain, we ran two experiments with rats of the Berkeley S_1 strain. On the day of birth, some animals received lesions directed to the occipital cortex, but in many cases subcortical damage also resulted; other animals were sham-operated. In Experiment I, half the rats lived in restricted environments and half in enriched environments from day 5 or 6 until about day 65; in Experiment II the differential environments were begun on day 25 and lasted until day 65. The rats were then pretrained and tested on the standard 12 Hebb-Williams problems. Both experiments yielded significant effects of brain status (lesioned vs. intact) and of environment (impoverished vs. enriched). The effects of environment attained higher levels of significance in Experiment II where the lesions were smaller than in Experiment I. Considerable generality was demonstrated for the effects of environment on behavioral recovery since it was obtained with both sexes, with large lesions in Experiment I and with relatively small lesions in Experiment II, with both immediate and delayed environmental therapy, and with shorter periods of enriched experience than had been employed previously. The length and width of the cerebral hemispheres were also found to be affected significantly both by lesions and by environmental treatment.

Effects of Differential Environments on Recovery from Neonatal Brain Lesions, Measured by Problem-Solving Scores and Brain Dimensions

Complex environments have been reported to aid behavioral recovery from neonatal brain lesions (Schwartz, 1964), neonatal malnutrition (Wells, Geist & Zimmerman, 1972; Tanabe, 1972), and neonatal thyroid deficiency (Davenport, in press). Exciting as these reports are, it must be acknowledged that such beneficial effects of enriched experience have not been found universally (e.g., Bland & Cooper, 1969; Cornwell & Overman, Note 1) nor has their interpretation gone unchallenged (e.g., Isaacson, 1975; Levine, in press). Because of the potential importance of such experiments for understanding processes of recovery of function and as a possible model for research on therapy with human patients, we undertook to replicate and to extend the often cited experiment of Schwartz. Schwartz made bilateral posterior cortical lesions by suction in day-old rat pups. He then raised the lesioned rats and sham-operated controls from day 5 to day 95 in either impoverished or enriched environments. When he then tested the rats in the Hebb-Williams maze (beginning at 135 days of age), he found significant effects of both brain lesions and environment, as well as a significant interaction term. He reported that early enrichment overcame the effects of neonatal lesions so completely that lesioned-enriched environment rats performed better than did sham-operated rats from the restricted environment.

In the two experiments reported here, we made lesions on day 1 as did Schwartz, but we decreased the duration of the differential environ-

mental treatment. In the first experiment, the duration was 60 days, and in the second experiment we not only decreased the duration to 40 days but we also delayed the start of the differential treatment until 25 days after the operations.

EXPERIMENT I

Methods

The methods followed, in the main, those of Schwartz (1964), although the strain of rats and the duration of differential experience differed from those of Schwartz. Certain other differences between our procedures and those of Schwartz will be noted below.

Subjects

The Ss were 42 male rats from the Berkeley S_1 strain, born within a range of 6 days. Of the 136 original Ss, 74 were lost because of postoperative infection or maternal cannibalism and one because of illness during testing. Before surgery all male pups were given to foster mothers; each foster mother received four pups who came from four different litters; two pups were designated to receive cortical lesions and two to receive sham operations. Ss were assigned at random to four groups: Impoverished condition-lesioned (IC-L), impoverished condition-sham operation (IC-S), enriched condition-lesioned (EC-L), and enriched condition-sham operation (EC-S). Sixty-three days after the last operation there remained 21 IC-S, 9 IC-L, 23 EC-S, and 9 EC-L rats. Nine IC-S and 10 EC-S rats were removed at random in order to leave approximately equal groups for training and testing; one EC-L rat died during testing.

Surgery

Surgery was performed on the day of birth. Ice was used to induce hypothermic anesthesia. Four min after being placed on the ice, S became immobile and ready for surgery. The hypothermia also caused peripheral vasoconstriction, thus reducing bleeding during surgery. A midline incision was made in the skin over the skull. In the case of the sham-operated pups the skull was left intact (whereas Schwartz invaded the skull of sham as well as of experimental pups); the skin was then sutured and the animal was placed under a lamp to warm up. In the case of the experimental pups, a no. 25 hypodermic needle was used to cut a bone flap over the posterior cortex of each hemisphere. Gentle suction was used to remove cortical material from each hemisphere; the pipette was a no. 19 needle with the sharp tip ground away. The bone flap was then replaced, the skin sutured, and the pup was rewarmed. Lesioned rats had the small toe of the left foot removed for later identification; sham-operated rats had the small toe of the right foot removed. A small amount of quinine mixed in Zephiran solution was applied to the region around the incision; the quinine was meant to discourage cannibalism.

Differential Environments

Impoverished environment. Postoperatively each "litter" of this group resided with a foster mother in a standard colony cage; these cages were in the same room as the large EC cages. When the pups were 22-23 days old, they were placed in individual cages in a separate isolation room, and they remained in this condition for about 40 days.

Enriched Condition. Postoperatively each "litter" of this group resided with their foster mother for 5 or 6 days in a standard colony cage. Then three litters and mothers were placed together in each of 5 standard EC cages (70 x 70 x 46 cm); about six objects from our pool of stimulus objects were placed in the cages daily, but care was taken not to disturb the animals. The females cared for pups regardless of litter membership. This occurs even if mothers are placed together in a cage with their own pups. Since cross-fostering was bound to occur in EC, and since we have found that cross-fostering affects certain brain measures (Will, Ropartz, Mack, Kempf, & Mandel, 1974), we made sure to cross-foster the IC rats as well. When the pups were 22-23 days of age, the foster mothers were removed. Some pups were regrouped so that there were four EC cages, each containing 12-13 pups. Food and water were available to both EC and IC rats ad libitum until the start of pretraining.

Pretraining and Testing

On day 65 or 66 of age, IC and EC rats were weighed, recaged and placed in adjoining individual cages on cage racks. Water but no food was available in each cage. The cages were numbered but there was no indication to the testers of the condition from which the rats had come. Henceforth their only food was mash available in the goal box, and body weight was brought down gradually to 80 percent of the value at the start of pretraining. Following a standardized procedure, rats were pretrained over 12 days; at the end of this time they ran through simple practice problems readily, 8 trials per day. They were then tested on

the 12 standard Hebb-Williams problems (Rabinovitch & Rosvold, 1951), one problem per day and 8 trials per problem. Three apparatuses were used, in three different test rooms, and almost equal numbers of rats from each condition were tested in each room. Initial and repetitive errors were scored, and running time was recorded. (An initial error is the first made in a given error zone on a given trial; repetitive errors are further errors made in the same zone on a given trial.) We noted the occasional trials in which a rat that was already performing well on a problem suddenly slowed down and started to explore; this was evident in terms of a slow gait and sniffing the floor or walls.

Sacrifice and Histology

Five days after the end of testing, the rats were killed by decapitation. The brain was removed, the dorsal surface was photographed along with a millimeter scale, and then the brain was placed in 10 percent formalin. From decapitation to placement in formalin, the elapsed time was about 4 min. Later the brains were sectioned with a freezing microtome. Two days before sectioning, the brains were rinsed and put in a 30 percent sucrose solution. Sections were 50 micra thick and were made perpendicular to the base of the brain. Every tenth section in the region of the lesion was mounted on a slide and used as a photographic negative to obtain enlarged prints of the lesion.

Measurements of the length and width of the cerebral hemispheres were made from photographs of the dorsal surface which had been enlarged 5 times. The length of a hemisphere was taken as the distance between the projections of the anterior pole and the posterior pole on the midline.

The width was taken as the greatest extent perpendicular to the midline. The two hemispheres were measured independently, and measures were made to the nearest 0.5 mm on the enlargements. The measures were made on photographs coded by rat number and the reader did not know the environmental condition in which any animal had been raised, although the presence of lesions was of course obvious. For most animals, the measures of the two hemispheres were averaged. In some cases the extent of a lesion precluded measurement of one hemisphere, and for such animals measures of the better hemisphere were used instead of the mean. To correct for small differences in photography and enlargement, all values were normalized by the individual scale measures. Reliability of these measurements was high; two sets of measurements of hemispheric length made independently by different individuals were found to correlate 0.989 with each other.

Results

Brain Lesions

Figure 1 shows the extent of the lesions on the dorsal surface, and it also indicates the total error score for each animal (sum of errors, trials 2-8, summed over all 12 problems). Typical examples of transverse sections through the lesions are shown in Figure 2. The

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Insert Figures 1 and 2 about here

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lesions were found to be considerably larger than desired, and some

subcortical tissue (corpus callosum and hippocampus) was damaged or removed in all rats, as Schwartz also reported of his experiment. In a number of cases the hippocampus spread up into the cortical cavity, as Bland and Cooper (1969) reported.

Inflicting relatively large lesions on day 1 had the further effect of reducing subsequent growth of the cerebral hemispheres. Measurement of the cerebral hemispheres revealed large and highly significant reductions in both length and width when operated rats were compared with controls ($p < .001$); see Table 1. The smaller size of the hemispheres in the lesioned rats allowed the superior colliculi to be seen in the dorsal views of their brains, as is apparent in Figure 1. The effect of lesions on cerebral dimensions did not result from differences in body weights because the groups showed only small and nonsignificant differences in body weights at the start of pretraining. Furthermore, the effect of lesions was restricted to the growth of the cerebral hemispheres and did not affect the cerebellum. (Cerebellar length could not be measured well on the photographs, but cerebellar width was virtually identical for all groups.) Environment also produced a significant effect on hemispheric length ($p < .05$), see Table 1, but this EC-IC effect was found only among the lesioned animals. There was not a significant environmental effect on width. Inflicting cortical lesions within 10 days of birth has been reported to reduce the growth of cortical bulk in both cats (Isaacson, Nonneman, & Schmaltz, 1968) and rabbits (Nonneman, 1970). Environmental treatments have also been reported to alter length of the hemispheres, although results have been

somewhat mixed, as we will review in the Discussion.

Insert Table 1 about here

Behavioral Scores

With the large lesions inflicted in this experiment, the effect of brain status on performance was considerably larger and more significant than the effect of the differential environments. (The effects of smaller lesions will be seen in Experiment II.) Figure 3A presents mean errors per rat on trials 2-8, summed over all 12 problems, with two somewhat different methods of scoring: Originally we computed total errors, and then we obtained a cleaner set of scores by removing errors made during clear cases of exploration. This was done by substituting for the error and time scores of the exploratory trial the scores of the immediately preceding trial on which exploration was not noted. When exploration occurred, it was usually on one of the last trials after successful runs. In the case of total error scores, analysis of variance demonstrated the effect of lesioning to be clear ($p < .001$), but the effect of environment ($p < .10$) failed to reach an acceptable level of significance. When errors made during exploration were eliminated, the effect of environment became significant ($p < .05$) and the effect of lesions remained highly significant ($p < .001$).

Analyses were also made of initial and repetitive errors. In two other experiments with rats lesioned at 30 days of age, both sorts of error scores were affected by environment as well as by lesions, with repetitive errors showing especially clear differences among groups

(Will et al.). In the present experiment, initial errors did not show a significant effect of environments but repetitive errors did ($p < .02$); lesions affected both sorts of errors at beyond the .001 level.

Running times (Figure 3B) also revealed significant effects of both lesions and differential environments. Whether or not allowance

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Insert Figures 3A and 3B about here

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was made for exploration, the environmental treatment was significant ($p < .05$), and the lesion affect was highly significant ($p < .001$). Thus the postoperative environment was found to exert a significant effect on several measures of problem-solving behavior, in spite of the large size of the brain lesions.

EXPERIMENT II

Methods

The methods followed those of Experiment I, with the following differences: Both female and male S_1 rats were used. Care was taken to make smaller lesions than in Experiment I. Each of 9 foster mothers was given 8 pups, two lesioned and two sham-operates of each sex. Each litter remained in a standard colony cage until the pups were about 23 days of age. The 54 rats that survived to this age were weaned and assigned at random to IC or EC cages. One EC cage was used for the males (6 lesioned and 8 sham-operated controls) and another EC cage housed the females (6 lesioned and 7 controls).

Results

The lesions were smaller than those in Experiment I, as intended. Compare the extent on the dorsal surface in this experiment (Figure 4) with the previous set (Figure 1). The subcortical invasions, although present in several animals, were smaller than in Experiment I; examples are seen in Figure 5. In most cases the hippocampus was intact, although its shape was usually distorted. With these smaller lesions, there were smaller but highly significant effects of lesions in reducing the length and width of the cerebral hemispheres; see Table 2. Environmental treatments also produced highly significant effects on both

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Insert Figures 4 and 5 and Table 2 about here

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measures, with EC brains growing larger than IC brains. Sex also helped to determine brain size; the females, whose body weight was only about 69 percent that of the males, showed significantly smaller brain dimensions ($p < .001$).

Behavioral Scores

Total errors per animal on trials 2-8, summed over all problems, are presented in Figure 6 (compare with Figure 3). The environmental effect is clearly significant ($p < .05$), and the lesion effect is highly significant ($p < .001$). Although the females in each condition made slightly more errors than the corresponding males, there is not a significant difference related to sex. (Smith, 1972, reported that females of the Carworth Europe strain made more errors than males on the Hebb-Williams maze, at beyond the .05 level of confidence.) When errors committed

during obvious exploratory behavior were subtracted out, the significances of differences remained unchanged.

Insert Figure 6 about here

Analysis of initial and repetitive errors yielded results similar to those of Experiment I. Lesions produced significant effects on both kinds of scores ($p < .001$), but an environmental effect was seen only on repetitive errors ($p < .02$). Running time (Figure 7) revealed a strong environmental effect ($p < .001$), whereas the comparable effect in Experiment I reached only the .05 level of significance. Thus the pattern of effects on both error and time scores was similar to that found in Experiment I, but the levels of significance of the environmental effects were higher in most measures in Experiment II.

Insert Figure 7 about here

DISCUSSION

Comparison among Results

Similarities and differences between the results of the two present experiments should be considered, as well as comparisons between them and the experiment of Schwartz (1964). Both of our experiments yielded significant effects of environmental treatment as well as of brain lesions, although the EC-IC effect was clearly smaller than the lesion effect. In our first experiment, the unfortunately large size of the

lesions, which substantially impaired the hippocampus as well as the cortex, may have overwhelmed the environmental effects. In fact, it is impressive that all the animals did improve their performance in spite of the extensive lesions that some of them had sustained. In Experiment II, in which the lesions were smaller and apparently comparable with those of Schwartz, the environmental effect showed up more clearly than in Experiment I, but environment still accounted for much less of the variance than did the lesions. Schwartz had reported that environments produced larger differences in Hebb-Williams scores than did lesions, with both effects significant at beyond the .001 level of confidence; his lesioned-rich environment rats averaged fewer errors than his intact-poor environment rats.

The difference in effectiveness of the environmental treatments between Schwartz's study and ours becomes all the more striking when it is realized that Schwartz's "poor environment" rats were housed in groups of 2 to 6 per cage, whereas our IC rats were housed in individual cages from 25 to 65 days of age; thus our rats suffered from greater restriction of experience. Differences between rich environment of Schwartz and our enriched condition probably did not importantly affect the results; at least we have found that the size of the EC cages or the particular stimulus objects do not seem to be critical (Rosenzweig & Bennett, in press). Here again, however, there was a difference in the social grouping, since Schwartz placed 4 to 8 rats in each rich environment cage, whereas we kept about 12 rats in each EC cage. Thus the social stimulation differed considerably more between our EC and IC treatments

than between Schwartz's rich and poor environments.

The duration of the differential environmental treatments may have been an important factor. It lasted 90 days in Schwartz's experiment versus 60 days in our Experiment I and 40 days in our Experiment II. (It should be remarked that the period in Schwartz's experiment has been cited in some articles as being 4 months rather than 3 months, but this is due to an error at one point in his article.) Note, however, that Experiment II, with the shorter EC-IC period, yielded clearer environmental effects than did Experiment I. Since our two experiments differed in other ways, it will be necessary to do further work to obtain direct information on effects of duration of differential experience on recovery from brain lesions.

It is possible that Schwartz's sham-operated rats did suffer from some brain damage, since he opened the skull in sham-operates as well as in the lesioned rats. We left the skulls of the sham-operates intact to avoid the possibility of brain damage, and thus there may have been a greater difference between lesioned and sham-operates in our experiments than in the experiment of Schwartz. Schwartz stated, however, that "Apparently such meningeal damage as may have occurred [in the sham operates] had no effect on the underlying cortex as judged by final histology" (p. 73).

Even though our results are not as striking as those of the single experiment of Schwartz, we have confirmed the beneficial effects of postlesion enriched experience with rats of another strain. We have also shown that the duration of the enriched experience can be reduced

to 60 or to 40 days without destroying the effect and, in Experiment II, that the enrichment need not begin for several weeks after the lesion. In experiments reported elsewhere, we have also found beneficial effects of enriched experience upon recovery from lesions inflicted at 30 days of age (Will, Rosenzweig, Bennett, Hebert, & Morimoto, Note 2) or at 120 days of age (Will & Rosenzweig, Note 3). The role of experience in behavioral and anatomical recovery from brain lesions may provide a useful model for neurological investigations of behavioral therapies.

Changes in Dimensions of Cerebral Hemispheres

The findings of altered length and width of the hemispheres complement a few earlier reports on effects of differential experience on dimensions of the brain. Altman, Wallace, Anderson, and Das (1968) reported that any of several treatments--4 months of operant conditioning, daily handling from day 2 to day 11, or rearing in an enriched environment for 3 months after weaning--led to a significant increase in cerebral length but to no change in width. Rosenzweig and Bennett (1969) found only nonsignificant 1 percent increases in both length and width in 30-day EC-IC experiments with rats and with gerbils. Walsh, Budtz-Olsen, Torok, and Cummins (1971) when showed that the duration of the experiment was an important parameter: In a 30-day EC-IC experiment neither the 1 percent differences in length nor width were significant, although the product of length x width was significant (2.2 percent difference, $p < .02$). But following 80 days of differential rearing, the EC-IC difference in length was significant (2.5 %, $p < .001$), the difference in width was nonsignificant, and the product of length and

again yielded a significant effect (2.8%, $p < .001$). In a further study, Walsh, Cummins and Budtz-Olsen (1973) reported that the 1.2% difference in length after 30 days was significant ($p < .005$) with a large enough N (22 pairs); nevertheless, the 30-day effect was only half as large as that previously found with 80 days of differential experience. No difference in width was found.

In our Experiment I, the effects on length and width after 60 days of EC or IC were very small in the nonoperated rats, which were comparable to the subjects of Altman et al. and of Walsh et al.; only among our lesioned rats were clear effects seen. In Experiment II, small but significant increases in both length and width were found after only 40 days of differential experience. We thus confirm the effects of experience on cerebral dimensions. Furthermore, Experiment II showed a significant effect of experience on width of the hemispheres ($p < .01$) as well as on length ($p < .001$), whereas previous workers have reported significant changes only in length. We also extend to the rat the finding previously made with cats and rabbits that neonatal lesions impair the subsequent growth of the brain. The fact that a lesion made early in life in one region of the brain significantly affects development of other regions should be kept in mind when interpreting results of neonatal lesions. As a joint consequence of the effects of early lesions and environment on brain growth, the EC-L rats thus had significantly larger brains than their IC-L counterparts; it remains for further research to determine whether this difference in brain development accounts, in part, at least, for the better learning of the EC-L than of the IC-L group.

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Table 1

Effects of Brain Lesions and of Environments on Dimensions of Cerebral Hemispheres

Condition	n	Length (mm) $\bar{X}$	Length (mm) S.D.	Width (mm) $\bar{X}$	Width (mm) S.D.
A. Means and standard deviations					
EC-S	13	13.97	0.40	7.01	0.17
IC-S	12	13.88	0.30	7.06	0.13
EC-L	8	12.83	0.36	6.31	0.27
IC-L	9	12.24	0.84	6.25	0.31
B. Lesion effects in percentages[a]					
EC-L vs. EC-S		-8.2		-10.0	
IC-L vs. IC-S		-11.8		-11.5	
All sham vs. All lesion		-10.0**		-10.7**	
C. Environmental effects in percentages[b]					
EC-S vs. IC-S		0.1		-0.7	
EC-L vs. IC-L		4.8		1.0	
All EC vs. All IC		2.6*		0.0	

[a] 100 x (lesioned mean minus sham mean)/sham mean

[b] 100 x (EC mean minus IC mean)/IC mean

* $p < .01$, ** $p < .001$. Significance was determined for the main variables (lesions and environments), but differences between groups were not tested.

Table 2

Effects of Lesions, Environment, and Sex on Dimensions of Cerebral Hemispheres

Condition	n	Length (mm) $\bar{X}$	Length (mm) S.D.	Width (mm) $\bar{X}$	Width (mm) S.D.
A. Means and standard deviations					
♂EC-S	8	14.07	0.33	7.07	0.08
♀ EC-S	7	13.80	0.21	6.85	0.17
♂IC-S	7	13.81	0.37	6.94	0.10
♀ IC-S	7	13.67	0.38	6.75	0.20
♂EC-L	5	13.77	0.16	6.71	0.13
♀ EC-L	6	13.35	0.47	6.64	0.14
♂IC-L	6	13.49	0.22	6.68	0.32
♀ IC-L	4	13.05	0.21	6.42	0.12
B. Lesion effects in percentages[a]					
♂EC-L vs. ♂EC-S		-2.1		-5.1	
♀ EC-L vs. ♀ EC-S		-3.3		-3.1	
♂IC-L vs. ♂IC-S		-3.3		-3.8	
♀ IC-L vs. ♀ IC-S		-4.5		-4.9	
All lesioned vs. All sham		-3.0**		-4.1**	
C. Environmental effects in percentages[b]					
♂EC-S vs. ♂IC-S		1.9		1.9	
♀ EC-S vs. ♀ IC-S		1.0		1.5	
♂EC-L vs. ♂IC-L		2.1		0.4	
♀ EC-L vs. ♀ IC-L		2.3		3.4	
All EC vs. All IC		1.6**		1.6*	

(Continued on next page)

Table 2 (continued)

Condition	n	Length (mm) $\bar{X}$	Length (mm) S.D.	Width (mm) $\bar{X}$	Width (mm) S.D.
D. Sex differences in percentages[c]					
♂ EC-S vs. ♀ EC-S		2.0		3.2	
♂ IC-S vs. ♀ IC-S		1.0		3.8	
♂ EC-L vs. ♀ EC-L		3.2		1.0	
♂ IC-L vs. ♀ IC-L		3.4		4.0	
All ♂ vs. All ♀		2.1**		2.7**	

[a] 100 x (lesioned mean minus sham mean)/sham mean

[b] 100 x (EC mean minus IC mean)/IC mean

[c] 100 x (male mean minus female mean)/female mean

* $p < .01$, ** $p < .001$. Significance was determined for the main variables (lesion, environments, and sex), but differences between the groups were not tested.

Figure Captions

Figure 1. Extent of lesions in Experiment I, shown on outlines of the dorsal aspect of the brains. Lesions were reconstructed from frozen sections. The locations and extents of the lesions were similar for the two lesioned groups, EC-L and IC-L. For comparison, outlines of brains of two sham operates are shown below the scale.

Figure 2. Coronal sections illustrating various types of lesions observed in Experiment I (left column, at level of the optic chiasm; right column, at level of the optic tracts). The top row is from a sham operate, and each other row represents a different lesioned rat. In some cases the hippocampus was largely destroyed unilaterally (e.g., in the right hemisphere in blocks B, D, F and H). Where the hippocampus was not badly damaged, it often herniated up through the cortical lesion (e.g., in the left hemisphere in blocks C, D, G and H). The width of each block represents 17 mm.

Figure 3. Errors and running times in Experiment I. A. Errors per rat on the last 7 trials of all 12 Hebb-Williams problems. The dashed columns show total errors, whereas the solid columns show errors after those made during exploration have been subtracted out. The vertical lines indicate $\pm$ one standard deviation of the scores from which exploration errors have been eliminated. B. Time per rat on the last 7 trials of all 12 problems. As for errors, total time and time minus exploration are shown.

Figure 4. Extent of lesions in Experiment II, shown on outlines of the dorsal aspect of the brains. Lesions were reconstructed from frozen sections. The locations and extents of the lesions were similar for the two lesioned groups, EC-L and IC-L. For comparison, the outlines of the median-sized sham-operated IC-φ is shown at the bottom right.

Figure 5. Coronal sections illustrating various types of lesions observed in Experiment II. (For comparison with control sections, see top row of Figure 2.) In this experiment the lesions invaded chiefly the cortex, and the intact hippocampus often herniated up to occupy the site of the cortical lesion (e.g., blocks A and B). When the hippocampus was damaged, it was less likely to herniate (e.g., C). In a few cases there was extensive damage to the hippocampus (e.g., D) as in Experiment I. The width of each block represents 15 mm.

Figure 6. Errors per rat on the last 7 trials of all 12 problems, Experiment II. The dashed columns show total errors, whereas the solid columns show errors after those made during exploration have been subtracted out. The vertical lines indicate $\pm$ one standard deviation of the scores from which exploration errors have been eliminated.

Figure 7. Running times per rat on the last 7 trials of all 12 problems. Conventions are as in Figure 6.

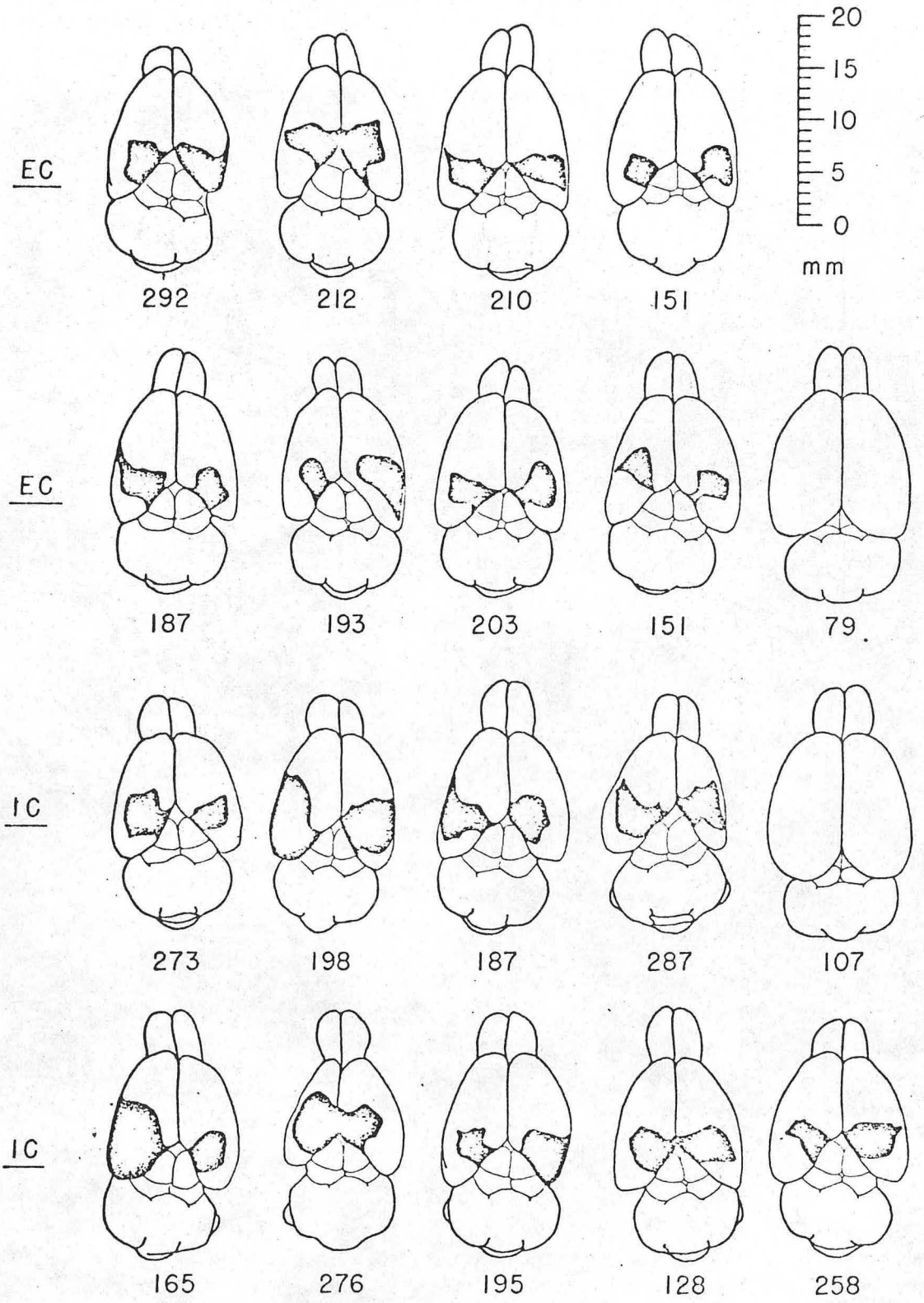

Fig. 1

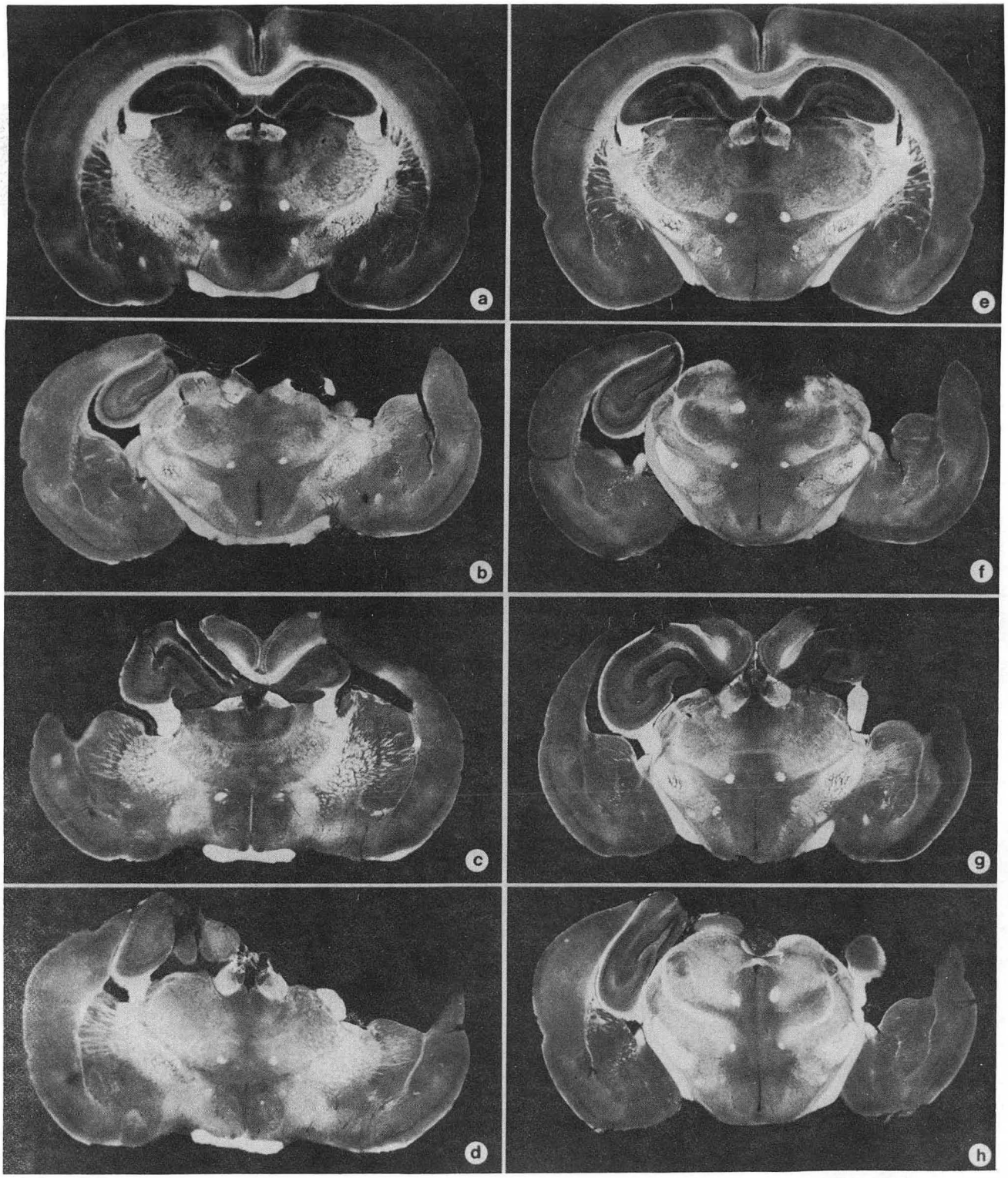

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Fig. 2

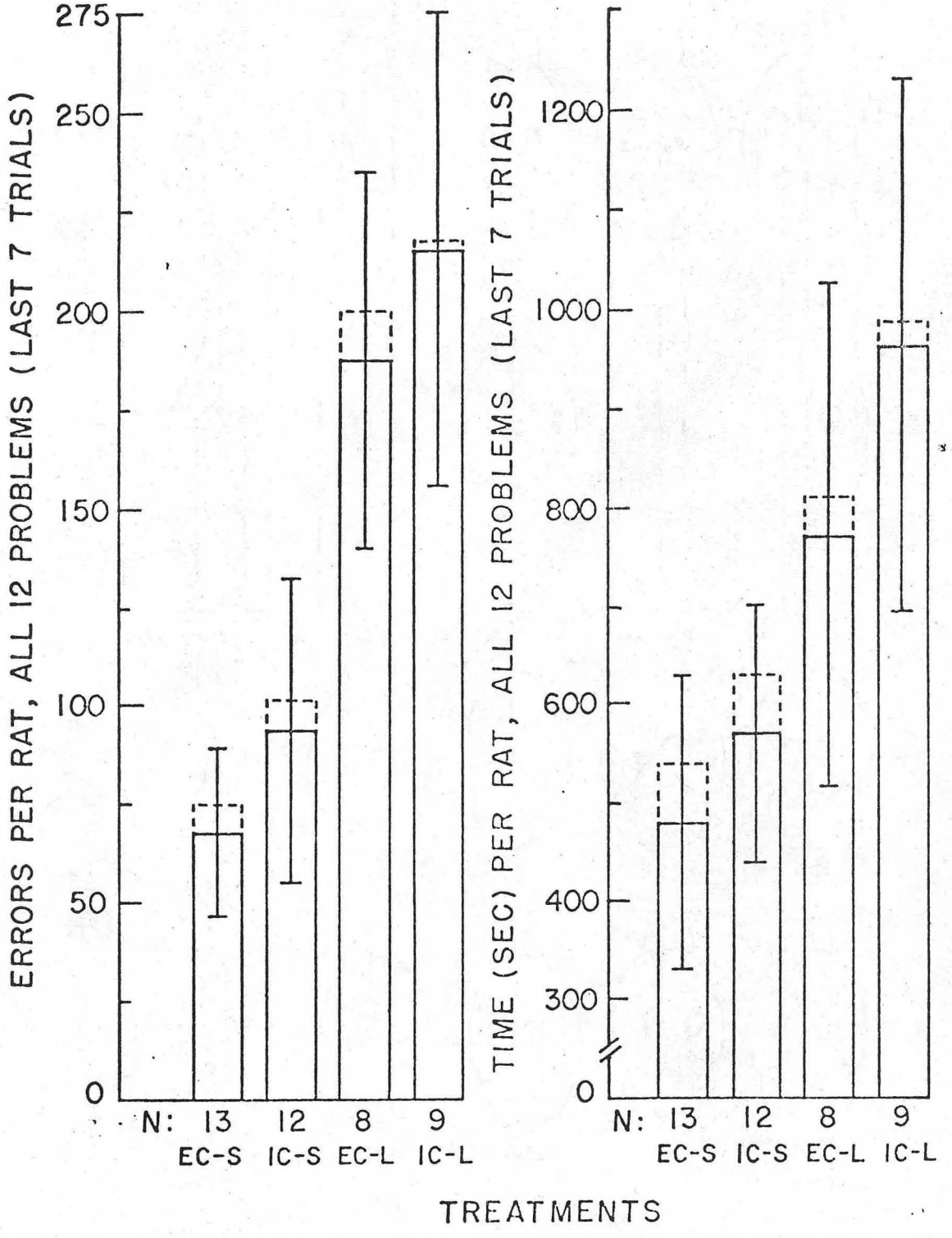

Fig. 3

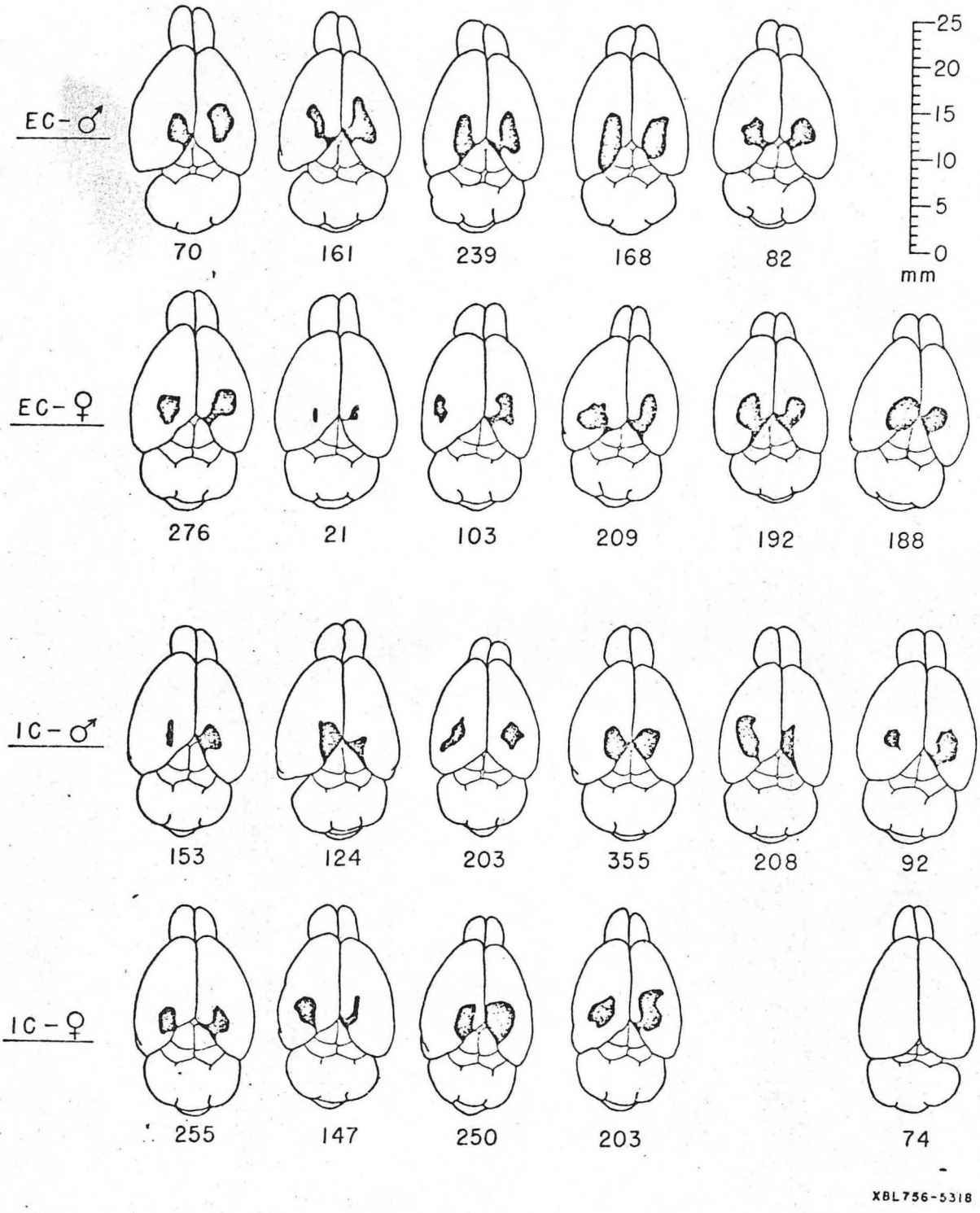
EC-♂
70
161
239
168
82
25
20
15
10
5
0
mm
EC-♀
276
21
103
209
192
188
IC-♂
153
124
203
355
208
92
IC-♀
255
147
250
203
74
XBL756-5318

Fig. 4

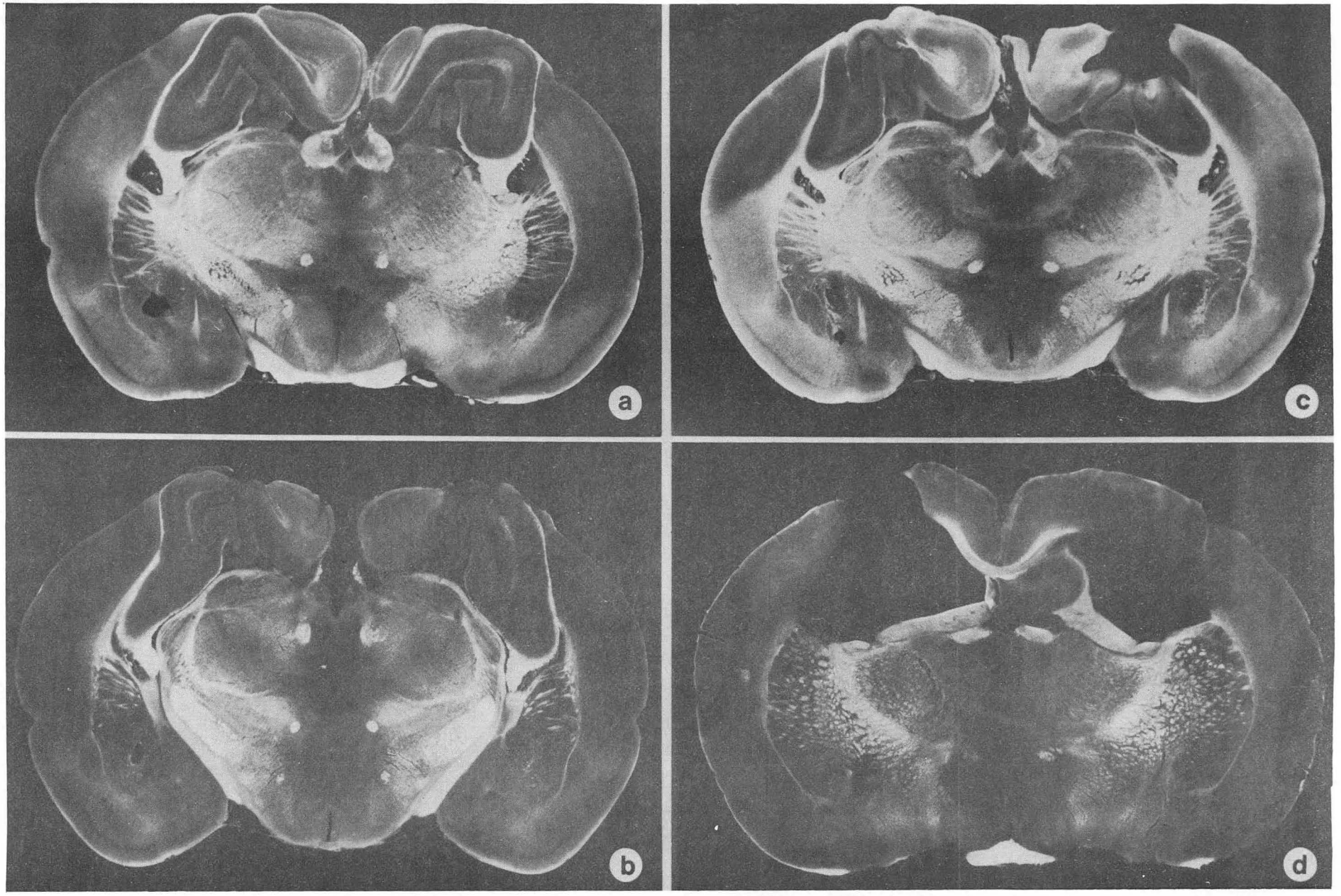

Fig. 5

XBB 763-2334

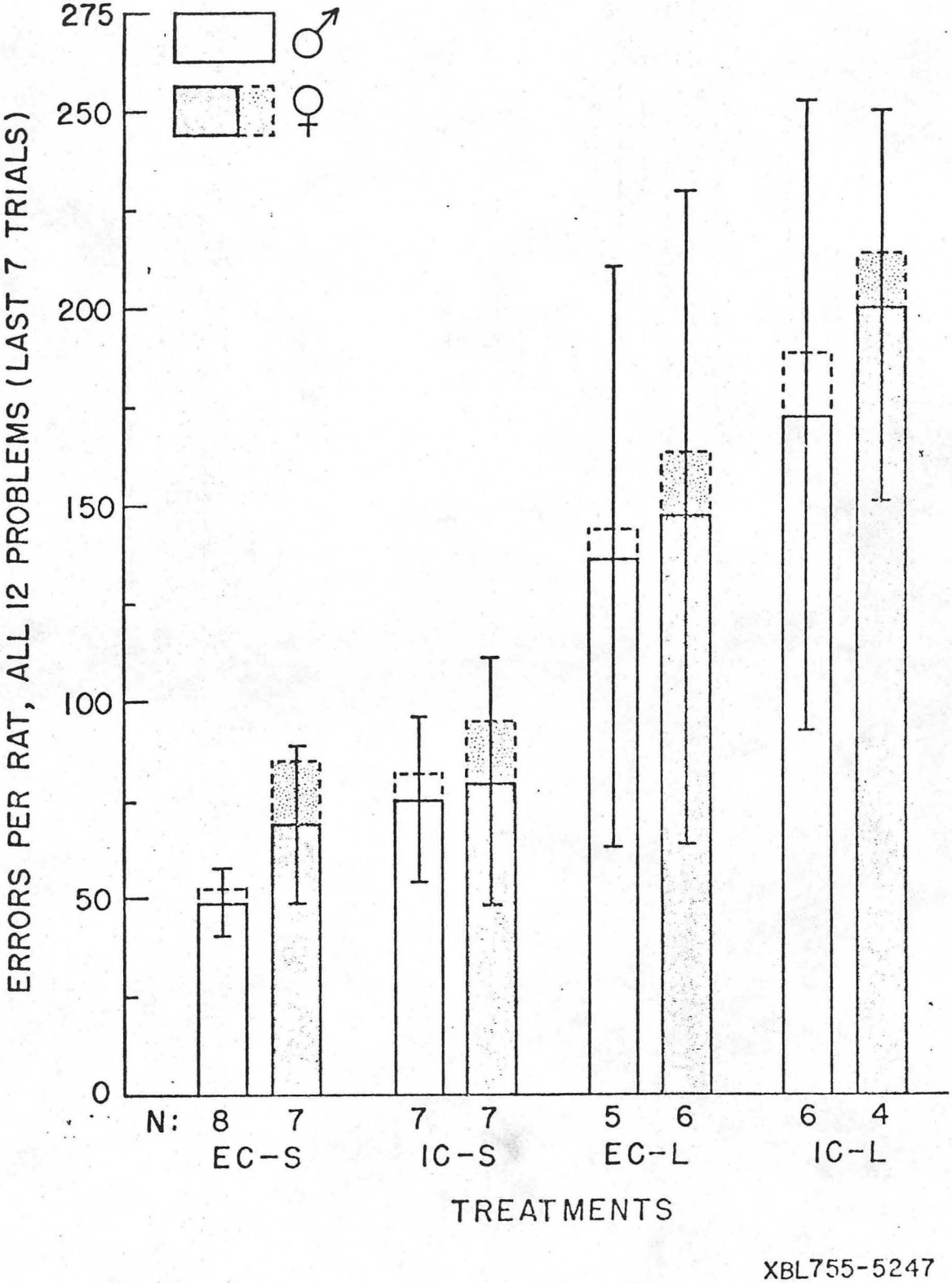
275
250
200
150
100
50
0
♂
♀
ERRORS PER RAT, ALL 12 PROBLEMS (LAST 7 TRIALS)
N: 8 7 7 7 5 6 6 4
EC-S
IC-S
EC-L
IC-L
TREATMENTS
XBL755-5247

Fig. 6

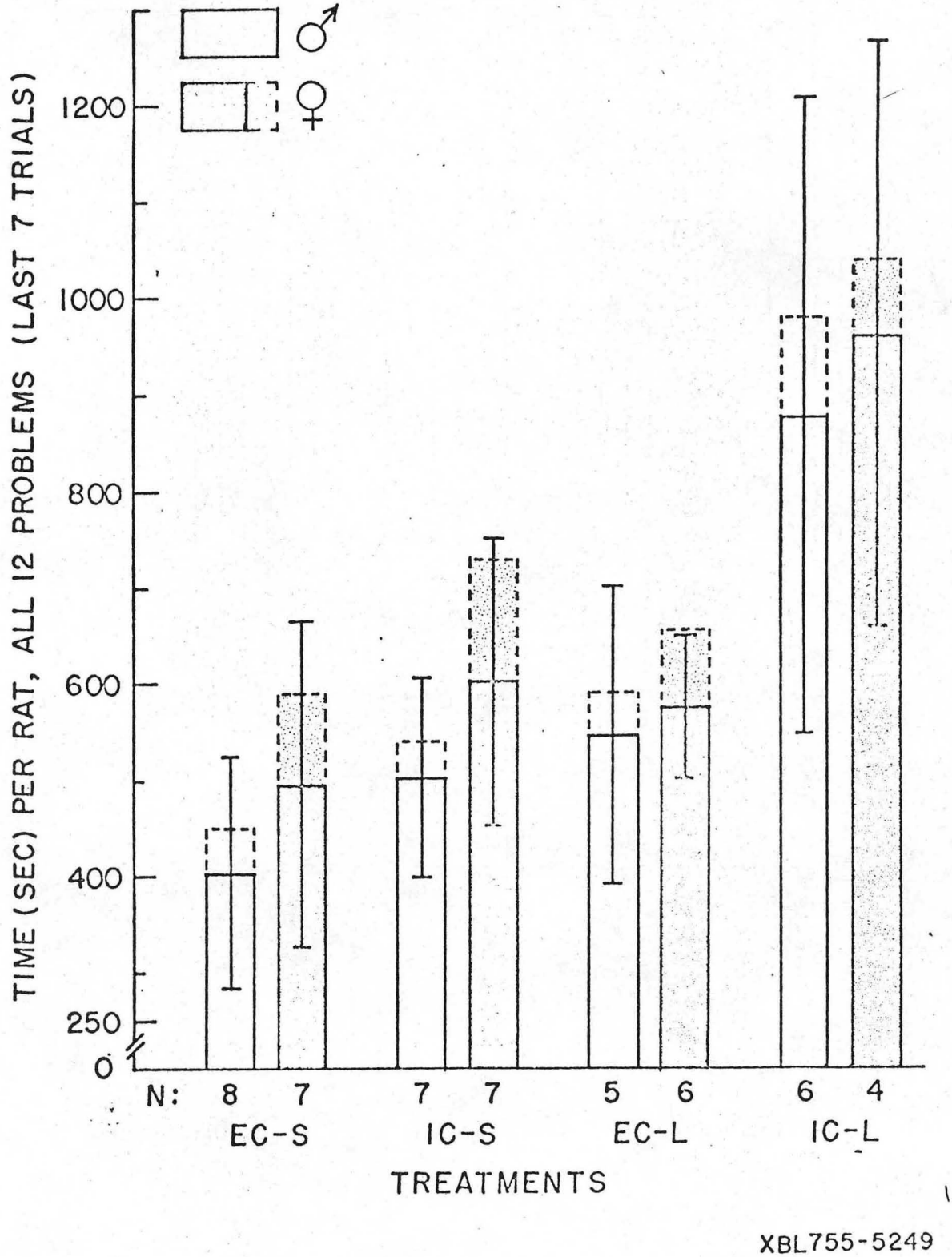

Fig. 7

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720