



Fig. 1. Relative spectral sensitivity of two pigeons determined with flicker photometry. The average data from four pigeons obtained with a tracking method (Blough, 1957) also are shown.

response level. Spectral sensitivity was taken as the logarithm of the reciprocal of the relative energy required to yield the criterion at each wavelength tested. Measurements were made at 10-nm intervals from 460-670 nm for Bird No. 258, and from 480-670 nm for Bird No. 483.

#### RESULTS AND DISCUSSION

The spectral sensitivity curves for the two pigeons are shown in Fig. 1. For comparison, Blough's data (1957) also are shown. It can be seen that there is substantial agreement in the sensitivity curves determined with Blough's tracking method and the flicker photometry results obtained in this experiment. It is likely that the processes underlying the sensitivity curves are the same in both cases.

One other comparison with Blough's psychophysical results can be made in regard to the reliability of the average sensitivity curves. The median standard error for Blough's data was 0.148 of a log unit calculated from the average data for four pigeons, whereas with flicker photometry data, the median standard error was only 0.035 of a log unit. This represents approximately a fourfold advantage of flicker photometry over the tracking method.

The standard error of measurement for each pigeon at each wavelength also was determined. This provides an estimate of the reliability of the individual bird's sensitivity. The errors of measurement for Bird No. 258 ranged from 0.003 to 0.2 of a log unit with a median of 0.06 of a log unit, and for Bird No. 483, from 0.01 to .09 of a log unit with a median of .05 of a log unit.

One approach that is commonly attempted with overall sensitivity curves is to speculate about possible underlying receptor systems. Ikeda (1965) performed such an analysis of his ERG data in relationship to his selective-adaptation data and Blough's overall spectral-sensitivity data. In brief, he concluded that the latter can be fitted by the simple average of two spectral curves determined by the ERG on-response (b wave) and the ERG off-response (d wave). The former has a peak at 547 nm, whereas the latter peaks at 605 nm. Although the data reported here are not inconsistent with this conclusion, it should be pointed out that the above set of spectral mechanisms do not exhaust the possible combinations that would yield a good fit to the overall spectral curve. One way to test Ikeda's conclusions would be

to perform selective-adaptation experiments using behavioral methods. If the overall spectral curves were partitioned in a manner congruent or similar to the electrophysiological curves, Ikeda's proposal would be on much firmer ground.

The data reported here indicate that flicker photometry is applicable to lower animals, and that the spectral curves obtained with this method are highly reliable. One additional advantage of this method is that the behavioral requirements for the animal are relatively simple, and they are easy to maintain.

#### REFERENCES

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#### NOTES

1. This research was supported by Grant NB MH 07222 from the National Institutes of Health, USPHS.

2. The assumption about how pigeons actually "perceive" the lights is not necessary. It is simply easier to talk about "steady" and "flickering" lights than it is to talk about high and low alternation rates.

## Correlations between error scores and the reversal index in rats<sup>1</sup>

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*during initial learning and errors during reversal learning (r = +.143).*

*Nineteen rats learned a spatial discrimination and reversal in a WGTA. There was a significant negative correlation between errors during initial learning and the reversal index (r = -.523, p < .05), a significant positive correlation between errors during reversal learning and the reversal index (r = +.679, p < .01), and a low positive correlation between errors*

Warren (1967) has shown that, for naive cats, the size of the reversal index (ratio of errors during reversal learning to errors during initial learning; see Rajalakshmi & Jeeves, 1965) is (1) significantly negatively correlated with number of errors made during initial learning and (2) significantly positively correlated with number of errors

Table 1  
Performance of 19 Rats on a Spatial Discrimination and Reversal in the WGTA

Initial Learning Errors	Mean	24.7
	Median	23.0
Reversal Learning Errors	Mean	37.0
	Median	37.0
Reversal Index	Mean	1.78
	Median	1.19
Correlations:		
Initial-Learning Errors x Reversal-Learning Errors	$\rho$	+0.098
	$r$	+0.143
Initial-Learning Errors x Reversal Index	$\rho$	-.318
	$r$	-.523 ( $p < .05$ )
Reversal-Learning Errors x Reversal Index	$\rho$	+0.854 ( $p < .01$ )
	$r$	+0.679 ( $p < .01$ )

made during reversal learning. Warren also presents data for naive rhesus monkeys that show the same trends. Since the number of errors made during the learning of a simple discrimination is not a sensitive index of phyletic differences in learning abilities (Warren, 1965), the fact that the reversal index is significantly correlated with error scores appears to limit the potential value of the reversal index as a tool in scaling intelligence (Warren, 1967).

An examination of unpublished data from an experiment by the present author, in which 15 rats learned a spatial discrimination and reversal under one of two levels of drive in a WGTA, suggested that the correlations noted by Warren might also hold for rats. The pooled data from this pilot study yielded a correlation ( $r$ ) of  $-.54$  between errors during initial learning and the reversal index, an  $r$  of  $+0.73$  between errors during reversal learning and the reversal index, and an  $r$  of  $+0.08$  between initial learning errors and reversal-learning errors. The present study was undertaken to replicate these pilot data under uniform motivational conditions.

#### SUBJECTS

The Ss were 20 male Sprague-Dawley rats purchased from Bio-Science Animal Laboratories, Oakland, California. They had previously served in a study of open-field behavior but were naive as regards either food deprivation or learning problems. Their weights at the beginning of the study ranged from 291-418 g.

#### APPARATUS

The apparatus was a WGTA for rats described in detail by Rollin, Shepp, & Thaller (1963). Two grey plastic cubes, 1½ in. on a side and weighing 24 g, covered the food wells. To obtain a reward pellet, S was required to displace one of the cubes with its nose by sticking its head out of one of two holes in the back of the holding cage whenever an opaque door separating the holding cage from the stimulus platform was raised. To control for any possible olfactory cues from the dry food

pellets used as rewards, both food wells contained Noyes pellets beneath an opaque porous plastic screen; the actual reward pellet was placed on top of the screen.

#### PROCEDURE

After being brought down to 85% ad lib weight, Ss received 3 days of pretraining during which they (1) learned to obtain Noyes pellets from the food wells when the door was raised, (2) learned to displace the cubes to obtain the pellets, and (3) had 10 free-choice trials to determine position preferences. One S had to be discarded at this point for failure to complete pretraining successfully. After pretraining, Ss received 20 noncorrection trials a day with a 10- to 15-sec ITI. S's nonpreferred side was the correct side on the initial problem. When S had made 18/20 correct responses on any one day, the problem was reversed the following day. Training continued until S met the 18/20 criterion on the reversal problem. Correct responses were rewarded with one 97-mg Noyes pellet.

#### RESULTS AND DISCUSSION

Table 1 shows the mean and median number of errors for both initial learning and reversal learning, the mean and median for the reversal index, and the rank-order and product-moment correlation coefficients among these three measures. The pattern of correlations follows closely that described by Warren (1967) for naive cats and monkeys: (1) The number of errors in initial learning and the reversal index were significantly ( $p < .05$ ) negatively correlated, (2) the number of errors in reversal learning and the reversal index were significantly ( $p < .01$ ) positively correlated, and (3) the number of errors in initial learning and the number of errors in reversal learning were unrelated ( $r = +0.14$ ). This is also the same pattern of correlations as emerged in the pilot data cited in the introduction.

These correlations indicate that, for naive rats, error scores during initial learning account for approximately 25% of the variance of reversal-index scores, and

error scores during reversal learning account for approximately 50% of the variance of reversal-index scores. Since neither initial errors nor reversal errors are useful in detecting learning-capacity differences between species (Warren, 1965), and since these measures account for a substantial portion of reversal-index variance, it follows that the reversal index itself will be of limited value in distinguishing between the learning capabilities of various species.

Finally, there is an indication in some of Warren's (1967) data that these relationships between performance measures described for naive Ss may not hold for experienced Ss. Warren (p. 497, Fig. 3) describes the WGTA performance of 13 cats which had previously learned a discrimination and reversal in a Grice box. These data show that, for experienced Ss, the relationship between errors during initial learning and errors during reversal learning was significantly positive ( $\rho = +0.81$ ). If not a sampling error, this change from a low positive correlation to a high positive correlation suggests that prior experience with discrimination and reversal learning changes a S (perhaps allowing it to habituate to certain general aspects of learning situations) so that its performance becomes more consistent. This possibility appears deserving of further study.

It is also interesting to note that, for the experienced cats, the relationship between errors during reversal learning and the reversal index was significantly negative ( $\rho = -.56$ ), as opposed to significantly positive for naive cats and rats (see Table 1 of the present study). That is to say, as both the numerator and denominator of the reversal index increased, the value of the reversal index itself decreased. This suggests that the relationship between errors during initial learning and errors during reversal learning (i.e., that line that describes negative transfer) is negatively accelerated rather than linear.

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#### NOTE

1. This work was supported by the President's Research Committee, University of British Columbia. Mr. Michael Judd assisted in the collection of data.