sediment, containing both mitochondrial and microsomal fractions, was suspended in appropriate amounts of 0.25*M* sucrose and supernatant fluid to yield a suspension containing particulate fractions and supernatant fluid equivalent to approximately 200 mg and 30 mg of liver, respectively, per 0.45 ml, the quantity of homogenate added to each of the experimental flasks.

In eight experiments rats were paired for age and weight; one received almost daily intraperitoneal injections of 100 μg of sodium thyroxin in 1 ml of 0.01*N* NaOH; the other received equivalent amounts of the NaOH solution alone. After at least six doses in 7 days, homogenates were prepared simultaneously from both animals as described above, and DL-leucine-1-C^{14} incorporation activity in both was measured in parallel flasks in a single combined experiment. Flask contents and incubation procedure are described in the title of Table 1. The reaction was terminated with 12-percent trichloroacetic acid, and the precipitated protein was purified and plated on filter paper by a modification of the method of Siekevitz (*6*). Sample weights were determined from difference in planchet weights before and after plating. Radioactivity was measured with a thin-window Geiger-Mueller counter; total counts collected were sufficient to yield a 3-percent coefficient of variation. Counting rates were corrected for background, self-absorption, and zero time controls. The results are summarized in Table 1. Although protein nitrogen concentrations, as determined by the micro-Kjeldahl technique, were identical in both groups (2.17 mg per flask), leucine incorporation was substantially greater in the homogenates from thyroxin-treated rats.

Table 1. Effects of thyroxin on DL-leucine-1-C^{14} incorporation into protein of rat-liver homogenates. To each flask (25-ml Erlenmeyer) were added 5 μmole of adenosine-5′-monophosphate, 20 μmole of potassium phosphate (*p*H 7.4), 5 μmole of $MgCl_2$, 50 μmole of potassium α-ketoglutarate, 0.8 μmole of DL-leucine-1-C^{14} (specific activity, 5.33 μc/μmole), and 0.45 ml of the appropriate homogenate prepared in 0.25*M* sucrose, as described in the text. In in vitro studies, 0.022 μmole of sodium thyroxin contained in 0.1 ml of 0.01*N* NaOH was added to the experimental flasks; all other flasks received equivalent amounts of the NaOH solution alone. The reaction mixture was brought to a final volume of 1.7 ml with 0.25*M* sucrose. Incubation in air was carried out with shaking in a water bath at 37°C for 1 hour. Zero time controls were included in all experiments.

Item	Activity (count/min mg of protein per hr)	
	Mean	Standard error
Thyroxin pretreatment in vivo (8 rat pairs)		
Normal rat	29.0	± 1.9
Hyperthyroid rat	42.3	± 3.0
Difference	13.3*	± 3.2
Effect (%)	+46	
Treatment with 1.3 × 10^{-5}M thyroxin in vitro (7 experiments)		
Control	26.9	± 1.8
Thyroxin-treated	31.9	± 2.3
Difference	5.0*	± 1.4
Effect (%)	+19	

* Denotes statistical significance; $p < .02$ (determined by method of paired comparison).

In order to localize the source of the increased activity, mitochondria and microsomes were prepared separately from livers of both types of animals by centrifugation at 15,000*g* for 15 to 20 minutes and 105,000*g* for 60 minutes, respectively. All possible combinations of mitochondria, microsomes, and supernatant derived from both homogenates were incubated as described above. Representative results of an experiment of this type are illustrated graphically in Fig. 1. It is clear that most, if not all, of the increased activity is localized in the mitochondrial (15,000*g*) fraction.

In Table 1 are also summarized the results of seven experiments in which the effects of $1.3 \times 10^{-5}M$ thyroxin added in vitro to normal rat liver homogenates were studied under the conditions specified. Although less pronounced, the effects were just as consistent as those observed with thyroxin administration in vivo, a stimulation occurring in every one of the experiments. Similar effects have been observed in several experiments with slightly altered conditions. The effect is erratic with more highly concentrated homogenates and is completely eliminated by doubling the Mg^{++} concentration. Preliminary observations indicate that increasing graded effects occur with thyroxin concentrations between 1×10^{-7} and $1 \times 10^{-4}M$. At $1 \times 10^{-3}M$, the effects of the uncoupling of oxidative phosphorylation supersede, and a marked inhibition of amino acid incorporation occurs, indicating a qualitatively different phenomenon.

To test the possibility that the thyroxin effects may be preservative rather than stimulatory, a few short-term incubations have been performed. The effects of thyroxin pretreatment in vivo are clearly not preservative; they are as great during the linear period of amino acid incorporation as at 60 minutes. The effects of thyroxin in vitro are less clear; they are distinctly present during the linear period but become more pronounced with longer incubation.

The results of these studies (*7*) suggest that uncoupling of oxidative phosphorylation is not a physiological action of thyroxin. They support, rather, the hypothesis that thyroxin stimulates energy-requiring processes, such as protein synthesis, and that its characteristic acceleration of oxygen consumption is secondary to the increased demand.

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Serial Errors in Human Learning: a Test of the McCrary-Hunter Hypothesis

Abstract. An experiment was conducted on 120 human subjects to test the hypothesis that the probability distribution of serial errors is an invariant property of rote memorization. Contrary to the hypothesis, the relative difficulty function was significantly affected by ability to learn. There was a systematic tendency ($p < .05$) for fast learners to commit proportionately more errors in the middle of the sequence.

The present communication reports an experimental test (*1*) of a hypothesis concerning certain learning phenomena advanced by McCrary and Hunter (*2*). Upon reexamining many classical serial position curves, in which distribution of practice had caused unequal reductions in errors at the central and extreme positions of a list, McCrary and Hunter conceived the idea of employing *relative* rather than *absolute* measures of difficulty. To this end, they replotted some earlier data by expressing the mean errors committed at each serial position "as a percentage of the total mean errors" (*2*). The results were as follows: (i) all curves had the typical skewed, bowed form which reveals subjects' greater difficulty with intermediate items than with initial or final items, and (ii) all curves had basically the same form, showing no consistent differences in trend under variation of work conditions.

From these findings, McCrary and

Hunter proceeded to an experiment in which 16 subjects memorized lists of nonsense syllables or familiar names. In contrast with the two divergent mean error curves, the percentage error curves appeared to coincide, as in the case of the distributed-practice data. However, when similar graphs were made of the performance of fast versus slow learners ($n = 8$ each) on the easier list, there was a tendency for the fast learners to make *proportionately* more errors in the middle and fewer errors at the beginning and end of the series. Unfortunately, McCrary and Hunter did not present any statistical evaluation of the differences, nor did they discuss this apparent departure from the other two sets of observations. They concluded that any factor which decreases difficulty in serial verbal learning, "including meaning, familiarity, and quick learning ability" (*2*, p. 133), will produce gains at each position which are proportional to the total number of errors made. The McCrary-Hunter hypothesis states, in other words, that the form of the *relative* difficulty-position function is an invariant property of serial verbal learning.

To obtain more extensive individual-difference data bearing on this hypothesis, an experiment was conducted in which 120 subjects practiced a serial list of eight two-syllable nouns for ten trials. The subjects were undergraduate psychology students enrolled at Montana State University in 1958, all naive with respect to serial learning. The items were selected from the central portion of Noble's (*3*) scale of meaningfulness (m), such that the mean median m-value was 3.52. A Stoelting memory drum was used to expose the series, the interstimulus and intertrial periods being 2 and 4 seconds, respectively.

Following tabulation of the learning scores, the sample was stratified into five homogeneous levels of initial ability (A) of ten subjects each. The basis of the A classification was the total number of correct responses made during trials 1 to 4. These representative levels contained 37 men and 13 women, whose ages ranged from 17 to 34 (mean 20.1 yr). Cumulative scores earned by the five groups fell in these ranges: group I (slow), 0; group II (below average), 2; group III (average), 4; group IV (above average), 6 to 7; and group V (fast), 9 to 15. The mean numbers of correct responses in each group were 0.0, 2.0, 4.0, 6.5, and 11.7, respectively. Difficulty values for each ability group were then computed on the basis of mean total errors (absolute difficulty) and mean percentage of total errors (relative difficulty) at the eight serial positions during trials 1 to 10. In determining the latter measurements, percentage scores were calculated for each subject separately before averaging over the group ($n = 10$). This procedure amounts to equal weighting by subjects rather than by responses and hence is statistically more valid than the short-cut of using total group errors per position as the divisor.

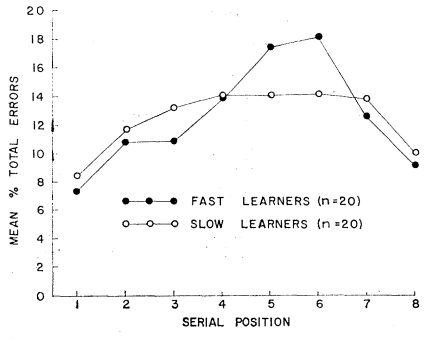

Fig. 1. Relative difficulty as a function of serial position, with learning ability as the parameter.

Table 1. Absolute versus relative difficulty (measured by mean total errors and mean percentage of total errors, respectively) of various serial positions as a function of initial ability level.

Ability group (A)	Serial position (P)							
	1	2	3	4	5	6	7	8
	Mean total errors							
I	6.5	8.3	8.9	9.2	9.2	9.5	9.1	7.1
II	4.6	7.2	8.3	9.2	9.1	8.9	8.9	6.1
III	3.0	5.1	7.0	7.6	9.1	7.9	7.9	5.9
IV	3.2	4.2	4.2	5.7	7.4	7.8	5.1	4.6
V	2.3	3.8	3.9	4.6	5.7	5.6	4.3	2.5
	Mean total errors (%)							
I	9.5	12.2	13.2	13.5	13.6	14.0	13.5	10.5
II	7.4	11.5	13.3	14.8	14.6	14.3	14.4	9.7
III	5.7	9.4	13.0	14.2	17.0	14.8	14.8	11.1
IV	7.5	10.5	9.9	13.4	17.4	18.6	12.1	10.7
V	7.1	10.8	11.7	14.1	17.4	17.9	13.2	7.8

Table 1 presents the general results of the experiment. From the *absolute* error measure in the upper half of the table, it is clear that difficulty is progressively reduced as initial ability level increases. When plotted, each frequency curve shows the classical bowed form, with the point of maximum difficulty just past the middle of the series. Turning now to the *relative* error measure in the lower half of the table, we find that the percentage curves tend to merge but are not identical. Instead, there is a disproportionate relationship between learning ability and the difficulty of the various serial positions. As a statistical test of the null (McCrary-Hunter) hypothesis that no real differences exist among the five groups when percentage measures are employed, an 8×5 type I mixed-factorial analysis of variance (*4*) was performed upon the relative error scores in Table 1. The main effect of serial position (P) is significant ($F = 30.87$; $df = 7/315$; $p < .001$); the main effect of initial ability (A) fails to reach the 5-percent level ($F = 2.25$; $df = 4/45$; $p > .05$); but the $P \times A$ interaction is significant ($F = 1.59$; $df = 28/315$; $p < .05$).

For our purposes, the most salient finding is the significant interaction variance, which means that the obtained differences in trend among the ability levels cannot reasonably be attributed to chance. Figure 1 illustrates graphically the systematic tendency of fast learners to make proportionately more errors in the middle and fewer errors at the beginning and end of the series. For clarity, groups I and II of Table 1 have been combined as "slow" learners while groups IV and V have been combined as "fast" learners. There is a striking resemblance to the comparable McCrary-Hunter graph (*2*, Fig. 5). Although our experiment confirms McCrary and Hunter's data, it thus paradoxically refutes the overgeneralized constancy interpretation offered by McCrary and Hunter.

We conclude that the form of the relative difficulty-position function is not an invariant property of rote memorization. At best, as in the case of certain laws of psychophysics, there is only a partial invariance in this domain. The probability distribution of errors in serial verbal learning is significantly affected by individual differences in ability to learn.

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