

EMOTIONALITY AND THE YERKES-DODSON LAW

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The Yerkes-Dodson Law (17) which states that the optimum motivation for a learning task decreases with increasing difficulty has been shown to hold for several species. See Young (18). It is the purpose of the present experiment to extend the range to include the rat. However, individual differences in drive strength are clearly important here, as may be seen from the current work showing the differential effect of anxiety on human learning (16). Recent evidence (8) supporting the identification of neuroticism as an autonomic drive (7) suggests that emotionality, as defined by defecation scores in Hall's open-field test (10), may be a relevant variable, since the lability of the autonomic nervous system probably underlies both neuroticism in humans and emotionality in rats (6, 10). Emotional rats will therefore be expected to show greater drive than non-emotionals in a situation in which the motivation used (air deprivation) is intense and of a kind likely to give rise to fear responses, and consequently to learn faster when the task is easy, but more slowly when it is hard. That is to say, the optimum drive level in the Yerkes-Dodson situation should be lower for the emotionals than for the nonemotionals. We may therefore predict an interaction between emotionality and the two variables of motivation and difficulty level which should themselves interact in the manner suggested by the Yerkes-Dodson Law.

METHOD

Apparatus.—The Y-shaped discrimination apparatus designed by Jonckheere (12) for sur-

face swimming was adapted for underwater use. This is a conventional Y unit with metal walls 2 ft. high and alleys 4 in. wide. The stem of the Y is 7 in. long and the arms make an angle of 52° to the center line. Vertical partitions across each arm, 7 in. beyond the bifurcation, extend from top to bottom of the alley and contain the discrimination panels. The Ss were forced to swim through the unit completely underwater by roofing in the alleys before the partitions with stainless steel hardware cloth just below the water level (9 in.). The discrimination panels were hung vertically and hinged below the surface of the water. They were made of frosted Perspex and each presented an illuminated area, 3½ in. square, at right angles to the line of sight from the bifurcation. Either could be locked into place, or left free, to be opened underwater by S to allow escape to the part of the alleys beyond the partitions which were not roofed in below the surface. From here, hardware cloth ramps gave access to a platform above water level.

The illumination was provided by two lamps in parallel in a 24-v. circuit. One lamp was located above water level behind each discrimination panel with its filament parallel to the panel. A fixed portion of a wire resistor could be switched into the circuit of either lamp in order to dim the intensity of the light shining through the adjacent panel, the other lamp being undimmed. The S was thus presented with a choice between a well lit and a less well lit avenue of escape from underwater. Three amounts of resistance were used; the greater the resistance the dimmer the light, yielding a greater difference between the illumination of the alleys, and an easier discrimination. Measurements with a light meter (Avo No. 2) indicated that this difference in illumination could be represented, in ascending order of difficulty, by the ratios 1:300, 1:60, and 1:15. These constitute the three levels of difficulty and are designated easy, moderate, and difficult.

A submersible cage, measuring 9 × 6 × 4½ in. wide, also made of stainless steel hardware cloth, was fitted with a sliding guillotine door which could be released from above the surface, thus allowing escape through the discrimination apparatus. Following a suggestion by Mason and Stone (14), the intensity of the air deprivation used as motivation was manipulated by detaining the Ss for different lengths of time submerged

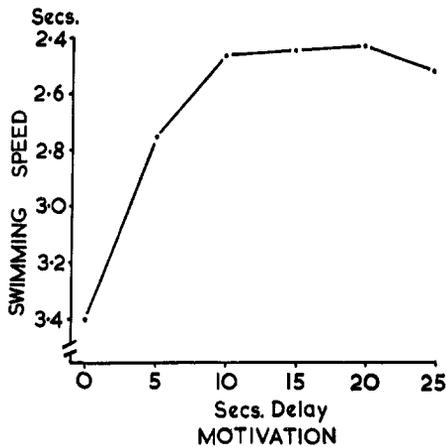


FIG. 1. The relationship between speed of swimming a 4-ft. straightaway underwater and intensity of imposed motivation (air deprivation) measured by the number of seconds delay underwater before release. Each point represents the mean time for 20 Ss; the data were collected on successive days.

underwater before releasing them to make the discrimination on which the promptness of their escape depended. Preliminary work, using 20 female rats as Ss, gave the results shown in Fig. 1. There is clearly no advantage in using delays longer than about 10 sec., since performance is not thereby improved. Indeed, delays longer than 20 sec. result in decreased swimming speed, presumably because of the effects of anoxia. Delays were therefore kept short, and delays of 0, 2, 4, and 8 sec. before release were selected, which represent approximately equal increments in swimming speed (see Fig. 1). These constitute the four levels of motivation.

Subjects.—Five replications of the $3 \times 2 \times 4$ factorial design (24 treatments) were used—that is, a total of 120 Ss was required. These 120 Ss were male albino rats which formed part of the second and third generations in a selective breeding study of emotionality being conducted in this laboratory (3). When Ss averaged 105.5 days of age ($SE \pm .25$), they were given the modified and standardized open-field test described in detail elsewhere (1). Briefly, Ss were exposed for 2 min. per day for four successive days in a circular arena $32\frac{3}{4}$ in. in diameter with white plywood walls $12\frac{1}{2}$ in. high. A battery of loudspeakers and of photographic lamps above the arena provided sound (“white” noise) and light fields whose intensity at floor level in the arena averaged 78 db. (ref. .002 dynes/sq. cm.) and 165 cp., respectively. The

average number of fecal boluses deposited per day constitute the emotional reactivity score, and only Ss scoring 3.3 or more were assigned to the emotional group (mean = 4.1, $\pm .15$), and only Ss scoring 1.3 or less were assigned to the nonemotional group (mean = .8, $\pm .17$). These two groups constitute the two levels of treatment in the emotionality variable; the difference between them is significant beyond the .1% level by *t* test.

The populations from which Ss were selected by virtue of their emotional elimination scores had been bred by brother \times sister mating from a heterogeneous Wistar stock. They had been reared under standard conditions which are described fully elsewhere (3). In brief, these conditions featured controlled temperature and light/dark cycle in standard living quarters, standard conditions of husbandry—diet, routine care, number of animals per cage, etc.—and the minimum of handling. Some of them had been used for breeding purposes in the interval between testing in the open field and in the underwater discrimination unit, which interval itself varied with Ss’ generation, but there is evidence (2) to suggest that neither the sexual experience, nor age differences of the order encountered, are likely to affect Ss’ emotionality as measured. The mean age when experimentation began of the 45 Ss belonging to the second generation was 322.0 days (± 6.09), and the mean age of the 75 Ss belonging to the third generation 213.4 days (± 3.31). This difference is highly significant ($P < .001$ by *t* test); accordingly, the possible effect of this age difference upon the scores analyzed was investigated. There was no significant difference by *t* test between the over-all means of the two groups for the learning score used (discussed later), but, as might be expected, the older Ss swam significantly more slowly ($P < .01$, by *t* test). It need not, however, be anticipated that any systematic bias is thereby introduced into the analysis of the speed score, since Ss had been assigned to treatments randomly. As a check, a χ^2 test of the proportions of Ss of the two age groups assigned to each treatment combination showed no significant difference from that existing in the total group (45:75).

Procedure.—The random assignments of Ss to the 24 treatment combinations was made by forming the 60 emotional Ss into 12 groups of five each, equated as far as possible with respect to defecation scores, and the 60 nonemotional Ss into a further 12 groups of five each, similarly equated. The groups thus formed were then randomly assigned, within the emotionality dichotomy, to the various treatment combinations. The Ss were tested in groups of 24 (one complete replication) on 15 successive days.

The first five days were devoted to preliminary training during which *Ss* were successively given surface and underwater swimming practice in a 3-ft. straightaway, at which time the appropriate detention periods for the different *Ss* were established, then practice in the underwater discrimination unit to familiarize them with the operation of opening the doors formed by the discrimination panels. During this time the doors were unlit, and one side of the *Y* unit was blocked at the bifurcation by a solid partition, thus forcing the rat to one side or the other, in order to avoid the development of position habits. The side by which escape was thus permitted was varied randomly by use of a Gellerman series (9). At the end of this training all *Ss* were leaving the starting cage promptly on release, and opening the escape doors without difficulty.

On the next 10 days, 10 trials per day—a total of 100 trials—were given in the apparatus with a choice of alleys permitted and differences in illumination between the panels. No other illumination was present in the darkened room containing the water tank except for a small recording lamp and a radiant heat lamp above the self-draining metal boxes in which *Ss* were kept in the intertrial intervals. This interval was maintained relatively constant for all *Ss* despite the variation in delay ranging from 0 to 8 sec. by running them in larger or smaller groups, respectively. The brighter side of the unit was designated correct and kept open; an *S* choosing the darker side where the panel was locked was thereby forced to retrace its way to the brighter side in order to escape. That is, the correction method was used. The bright side was selected since it was constant for each of the three levels of difficulty, and because there was no tendency for *Ss* to prefer one side over the other. Thus, on the first trial upon which a choice was permitted, 56.7% went to the right-hand or bright side, and 43.3% to the dimmer one on the left. The difference from chance expectation yields a nonsignificant χ^2 . The "correct" side was randomly varied from trial to trial by use of a selection of 10 Gellerman series, the same ones being used in the same order for all *Ss*. The water temperature was maintained at 20° C., the air temperature during testing averaged 19.5° C. ($\pm .21$).

The time from the moment when the door of the starting cage was released until *S*'s snout broke the surface of the water beyond the illuminated panel through which it had passed was recorded to the nearest $\frac{1}{10}$ sec. by stop watch, and errors, defined as any entry into the "incorrect" alley of *S*'s head and shoulders or more, noted. These constitute the time and error scores, respectively.

The five replications of the experiment were tested at intervals over 4 mo. and were followed by a partial replication which supplied substitutes for the three *Ss* which died during experimentation and the seven whose results were excluded because they developed position habits. A position habit was defined for this purpose as the choice on two days (20 trials) or more during the last five days of testing of one side—left or right—exclusively.

RESULTS

The number of errorless trials out of the 100 trials given was counted for each *S* and the data subjected to a three-way analysis of variance after Pearson and Hartley's test (15) had disclosed no significant inhomogeneity of variance. The results are presented in Table 1. The *F* ratios for the difficulty and motivation main effects were calculated by using the Difficulty \times Motivation interaction variance estimate, in view of the significance of the interaction between these two variables. The nature of this interaction is indicated in Fig. 2. Table 2 shows the mean scores and *SD*'s for the various levels of the two treatments having significant main effects. These data indicate the efficacy of the experimental manipulation of these two independent variables.

TABLE 1
ANALYSES OF VARIANCE OF LEARNING
AND SPEED SCORES

Source	df	Number of Correct Trials		Average Time to Swim 21 In.	
		<i>MS</i>	<i>F</i>	<i>MS</i> †	<i>F</i>
Difficulty (D)	2	2260.2	23.5**	2.17	1.8
Motivation (M)	3	143.7	1.5	4.73	4.0**
Emotionality (E)	1	114.1	3.0	7.21	6.1*
D \times M	6	96.1	2.5*	1.05	0.9
D \times E	2	48.9	1.3	0.73	0.6
M \times E	3	77.8	2.1	2.48	2.1
D \times M \times E	6	54.9	1.4	1.21	1.0
<i>Ss</i>	96	38.0		1.18	
Total	119				

* *P* = .025.

** *P* = .01.

† Units 1/10 sec.

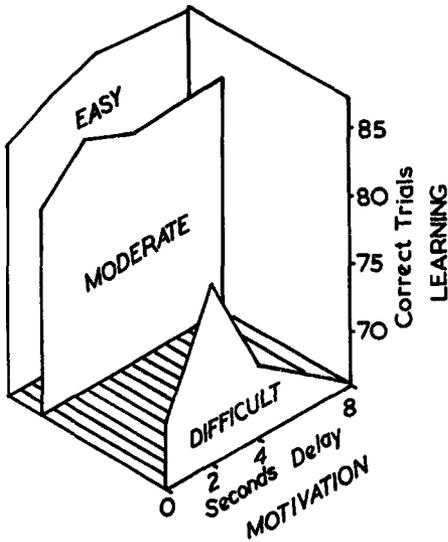


FIG. 2. A three-dimensional surface showing the relationship between learning scores in a discrimination task and (a) the intensity of the imposed motivation (air deprivation) measured by the number of seconds' delay underwater before release and (b) the level of difficulty of the task. The lamina are spaced to represent the over-all mean score for the appropriate difficulty level (see Table 2). Each point represents the mean score for 10 Ss.

Thus, each increase in the difficulty of the discrimination yields a significantly lower learning score, reaching the .01 level (by 1-tail *t* test) in the case of the easy vs. moderate difference, and the .001 level in the case of

the moderate vs. difficult one. Increasing the time of air deprivation first increased the mean learning score significantly (0- vs. 2-sec. delay), then caused a significant decline from the peak value (2- vs. 8-sec. delay; $P < .05$ in both cases by *t* test). This latter finding is comparable with that of many workers reporting a curvilinear relationship between motivation and performance when increasingly intense motivation is employed (see also Fig. 1).

It is clear from these results that the Yerkes-Dodson Law may be taken as confirmed. The optimum motivation for a discrimination task demonstrably decreases with increasing difficulty of the task. This effect, represented by the first-order interaction between the difficulty and motivational treatments, is significant at a satisfactory level, and part of the prediction is thus verified. It is equally clear that the prediction, as made above, relating to the effects of emotional reactivity on this complex relationship is not fulfilled. The trend of the results is partly in the predicted direction. Thus emotionals learn the easy discrimination faster than nonemotionals, and are about equal on the moderately difficult one, and similarly learn faster under low

TABLE 2
BREAKDOWN OF LEARNING SCORES

Motivation Level (Air Deprivation)	Difficulty of Discrimination							
	Easy		Moderate		Difficult		All	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0 sec.	84.8	6.6	81.3	6.3	71.1	9.0	79.1	9.4
2 sec.	86.4	4.7	84.7	5.9	79.5	4.8	83.5	6.0
4 sec.	87.7	3.9	83.0	7.1	71.6	6.2	80.8	9.0
8 sec.	86.8	3.9	83.2	5.9	66.1	6.5	78.7	10.6
All	86.4	5.0	83.1	6.5	72.1	8.3	80.5	9.1

motivation, and are about equal at medium levels. But on the difficult discrimination or under the most intense motivation used they again show a slight superiority. Consequently, the emotional Ss show an over-all superiority in learning, which, however, does not reach significance, and this is reflected in the failure of the one second-order and the two remaining first-order interactions, all of which involve the emotionality variable, to reach significance.

If it is conceded that the curvilinear relation involved makes such a procedure permissible, the partial success of the prediction relating to drive level and emotionality can readily be demonstrated. An analysis of variance based on the first two lowest levels of motivation only—that is, before the decline in learning associated with motivation greater than the optimum begins (see Fig. 2)—shows two significant effects. The first is the expected and highly significant one associated with level of difficulty, the second is the first-order interaction between Motivation and Emotionality ($P < .05$). This effect may be summarized by saying that the emotional Ss show superior learning under the minimal motivation used, but that this advantage disappears with the increase of motivation from 0 to 2 sec. delay before release.

Another way to investigate the relation of emotionality to drive level is to consider the *speed* of the response made to the motivational stimulus, irrespective of whether or not it resulted in improved learning. In order to derive a speed score for each S, and one which reflects its speed of swimming independent of the degree of learning attained, the time scores for the first day upon which all 10 trials were recorded as correct were aver-

aged. In this way the individual Ss' speeds may be compared at exactly comparable points on their respective learning curves. Since the distance swum in the apparatus is essentially the same for each S making a "correct" choice (21 in.), the time scores can be used directly for the purpose, as was done in preparing Fig. 1, thus avoiding the difficulty relating to averaging time over distance scores discussed by Crespi (5). For the 13 Ss assigned to the difficult discrimination who never learned it to perfection, the average of the last day's trials was calculated, omitting times for those trials when incorrect choices were made. An analysis of variance performed on these data after no significant inhomogeneity of variance had been demonstrated gave results which are also shown in Table 1. From this analysis it will be seen that the superiority of the emotional Ss over the nonemotional Ss in speed of swimming reaches satisfactory significance. The mean time scores are 1.80 and 1.96 sec., respectively. Inserting these values on a plot of swimming speed against motivational delays (like Fig. 1) shows that the difference of .16 sec. is equivalent to the effect on over-all speed scores of an increase in motivational delay of about 4 sec. Moreover, this effect is not significantly associated with any of the other variables in the analysis, from which it can be concluded that the emotionally reactive rats display a characteristically higher level of drive, which, within the limits of the present experiment, is not affected by the intensity of the motivation imposed. It may also be noted from this analysis that the absence of a significant effect for Difficulty shows that the speed score selected was in fact independent of the degree of learning, and that the significance of Motivation confirms the

efficacy of the experimental manipulation of the air deprivation variable. Thus, the mean time taken to swim 21 in. underwater decreased progressively from 1.98 sec. for 0 sec. delay to 1.97 for 2 sec., to 1.85 (4 sec.), and finally to 1.71 (8 sec.). The *SD*'s are .48, .33, .31, and .25 sec. respectively. Only the differences between each of the first three levels (0, 2, and 4 sec.) and the last one (8 sec.) reach significance (.05 level or beyond by 1-tail *t* test).

DISCUSSION

The confirmation of the Yerkes-Dodson Law reported here gains in interest because it employed a different species from those hitherto used in demonstrating the principle, and because it occurred under rather different experimental conditions. The motivation in particular was very different from that used in any of the other studies of the Yerkes-Dodson Law; the electric shock previously employed as an aversive stimulus was eschewed because of the difficulty of controlling it, and because of its disruptive effect, especially when strong, upon early learning. Air deprivation as used shares with shock the quality of being a rather intense stimulus, and the advantage of being manipulable within the testing situation. It has, in addition, been shown in practice to be easily varied in intensity.

It is true that in both this and the original study a visual brightness discrimination was used as the method of varying the degree of difficulty of the learning tasks. The resemblance hardly goes beyond the semantic, however. The similarity between the actual pieces of apparatus used is slight. The Yerkes box has been described as "spectacularly inefficient" (13), whereas the underwater discrimination technique as used in this study gave rapid learning without undue preliminary training.

The results obtained from the original study and the present one are surprisingly similar. A comparison of Fig. 2 with

that given by Yerkes and Dodson (17, p. 479) shows that the optimum motivation is in general slightly lower in the scale used than that encountered by them, and that there is no level of difficulty for which an optimum was never reached as was the case with their easiest discrimination. An increasing sharpness of the optimum peak with increasing difficulty is characteristic of both graphs. The dissimilarities mentioned can all be ascribed to differences in the levels of motivation selected. The relation of motivation to degree of learning is typically curvilinear, a decrease in learning following motivation more intense than the optimum, so it is not always easy to select suitable levels of motivation to reveal the optimum learning, especially if it is required to include different optima associated with different levels of difficulty, and more especially with a novel motivation like air deprivation about which little is so far known.

The confirmation of the Law is the more striking because of this difference in motivation. The needs arising from electric shock and from air deprivation are different physiologically, though they both give rise to drives mediated, in part, by fear. The further generalization of the Law must await experimentation using other situations and other drives, but the outlook is promising in view of the analogies in the human field already existing.

The possible role of anoxia must not be overlooked in connection with the use of air deprivation, since it is known (11) that it can cause learning defects comparable to those caused by electroconvulsive shock. It seems unlikely, however, that air deprivation of the duration used here can have led to anoxic damage to the nervous system sufficient to account for the curvilinear relation with learning. To the arguments which lead Mason and Stone (14) to reject this explanation of their comparable findings, we may add the following germane considerations from this experiment. Firstly, if anoxia were important in this connection, it would be reasonable to anticipate that all the groups subjected to

the greatest air deprivation would show a decrement in learning. A glance at Fig. 2 shows that this is not the case. Secondly, the analysis of the speed of swimming showed no significant difference between the difficulty levels (see Table 1). Now, the *Ss* assigned to the difficult discrimination had, at the time when the speed scores were selected, experienced much more air deprivation than had the other groups. They had made many more errors obliging them to hold their breath longer before escape, and they had also undergone many more trials. Neither of these circumstances, likely to increase any deficit ascribable to anoxia, depressed swimming speed, however.

The drive characteristics of emotionality as defined by open-field defecation scores are only partly elucidated by this experiment. Emotionally reactive *Ss* have a significantly higher speed of swimming—that is, they respond more vigorously to the same degree of imposed motivation. To this extent, they may be regarded either as having a higher drive level in general or as more susceptible to drive arousal. Further work to investigate the speed of swimming of these *Ss*, and employing a situation designed to demonstrate the Crespi effect (5) consequent upon changes in drive level, confirms the superior speed of the emotionals and the presence of the “elation” effect but indicates that they do not respond more to a sudden increase in drive than do the nonemotionals (4). It thus seems that drive level rather than drive arousal is involved.

Yet this higher drive level did not in general effect learning in this experiment in the manner expected. It seems unfruitful to enter into detailed speculations about the reasons for this seeming paradox—suffice it to say that it is probable that the situation used here is too complex to expect that any definitive solution may be found in the present data. Nevertheless the general finding relating to drive level does have some bearing on the postulated relation between emotionality in rats and neuroticism in humans. This cross-species identifica-

tion is not directly verifiable, but it can be cautiously said that the present results, at the very least, do nothing to render it improbable.

SUMMARY

The experiment was designed to test the validity of the Yerkes-Dodson Law and to investigate some of the drive characteristics of emotionality of rats. In a $3 \times 4 \times 2$ factorial design having five replications, 120 male albino rats were used as *Ss*. Three levels of difficulty of an underwater brightness discrimination, four levels of motivation deriving from different degrees of air deprivation, and two levels of emotionality defined in terms of defecation scores on the open-field test were used. Time and error scores from 100 trials were secured.

Analysis of variance of the results shows that the Yerkes-Dodson Law, as demonstrated by an appropriate interaction between difficulty and motivation, is confirmed at an acceptable level of significance. The prediction relating to the effects of emotionality on motivation is only fulfilled in part; a significantly higher drive level of emotionals as shown by their swimming speed is shown.

REFERENCES

1. BROADHURST, P. L. Determinants of emotionality in the rat: I. Situational factors. *Brit. J. Psychol.*, 1957, **48**, 1-12.
2. BROADHURST, P. L. Determinants of emotionality in the rat: II. Antecedent factors. *Brit. J. Psychol.*, in press.
3. BROADHURST, P. L. Emotionality in the rat: a study of its determinants, inheritance and relation to some aspects of motivation. Unpublished doctor's dissertation, Univer. London, 1957.
4. BROADHURST, P. L. A note on a “Crespi effect” in the analysis of emotionality as a drive in rats. *Brit. J. Psychol.*, in press.
5. CRESPI, L. P. Quantitative variation of incentive and performance in the white rat. *Amer. J. Psychol.*, 1942, **55**, 467-517.
6. EYSENCK, H. J. *The structure of human personality*. London: Methuen, 1953.
7. EYSENCK, H. J. A dynamic theory of anxiety and hysteria. *J. ment. Sci.*, 1955, **101**, 28-51.
8. EYSENCK, H. J. Reminiscence, drive and personality theory. *J. abnorm. soc. Psychol.*, 1956, **53**, 328-333.
9. GELLMAN, L. W. Chance orders of alternating stimuli in visual discrimina-

- tion experiments. *J. genet. Psychol.*, 1933, **42**, 206-208.
10. HALL, C. S. Emotional behavior in the rat. I. Defecation and urination as measures of individual differences in emotionality. *J. comp. Psychol.*, 1934, **18**, 385-403.
 11. HAYES, K. J. Anoxic and convulsive amnesia in rats. *J. comp. physiol. Psychol.*, 1953, **46**, 216-217.
 12. JONCKHEERE, A. R. A study of "fixation" behaviour in the rat. Unpublished doctor's dissertation, Univer. London, 1956.
 13. McCLEARN, G. E., & HARLOW, H. F. The effect of spatial contiguity on discrimination learning by Rhesus monkeys. *J. comp. physiol. Psychol.*, 1954, **47**, 391-394.
 14. MASON, W. A., & STONE, C. P. Maze performance of rats under conditions of surface and underwater swimming. *J. comp. physiol. Psychol.*, 1953, **46**, 159-165.
 15. PEARSON, E. S., & HARTLEY, H. O. *Biometrika tables for statisticians*. Vol. 1. Cambridge, Eng.: Cambridge Univer. Press, 1956.
 16. TAYLOR, J. A. Drive theory and manifest anxiety. *Psychol. Bull.*, 1956, **53**, 303-320.
 17. YERKES, R. M., & DODSON, J. D. The relation of strength of stimulus to rapidity of habit-formation. *J. comp. Neurol. Psychol.*, 1908, **18**, 459-482.
 18. YOUNG, P. T. *Motivation of behavior*. New York: Wiley, 1936.

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