1

OUTLINE OF A THEORY OF PUNISHMENT

BY

W. K. ESTES

TECHNICAL REPORT NO. 123

October 1, 1967

PSYCHOLOGY SERIES

INSTITUTE FOR MATHEMATICAL STUDIES IN THE SOCIAL SCIENCES
STANFORD UNIVERSITY
STANFORD, CALIFORNIA

53

TECHNICAL REPORTS

PSYCHOLOGY SERIES

INSTITUTE FOR MATHEMATICAL STUDIES IN THE SOCIAL SCIENCES

(Place of publication shown in parentheses; if published title is different from title of Technical Report, this is also shown in parentheses.)

1 D. Davidson, S. Siegel, and P. Suppes. Some experiments and related theory on the measurement of utility and subjective probability. August 15, 1955. (Experimental test of the basic model, Chapter 2 in Decision-making: An Experimental Approach. Stanford Univ. Press, 1957)

2 P. Suppes. Note on computing all optimal solutions of a dual linear programming problem. November 15, 1955.

3 D. Davidson and P. Suppes. Experimental measurement of utility by use of a linear programming model. April 2, 1956. (Experimental test of a linear programming model, Chapter 3 in Decision-making: An Experimental Approach. Stanford Univ. Press, 1957)

4 E. W. Adams and R. Fagot. A model of riskless choice. August 7, 1956. (Behavioral Science, 1959, 4, 1-10)

5 R. C. Atkinson. A comparison of three models for a Humphreys-type conditioning situation. November 20, 1956.

6 D. Scott and P. Suppes. Foundational aspects of theories of measurement. April 1, 1957. (J. Symbolic Logic, 1958, 23, 113-128)

7 M. Gerlach. Interval measurement of subjective magnitudes with subliminal differences. April 17, 1957.

8 R. C. Atkinson and P. Suppes. An analysis of two-person game situations in terms of statistical learning theory. April 25, 1957. (J. exp. Psychol., 1958, 55, 369-378)

9 R. C. Atkinson and P. Suppes. An analysis of a two-person interaction situation in terms of a Markov process. May 29, 1957. (In R. R. Bush and W. K. Estes (Eds.), Studies in Mathematical Learning Theory. Stanford Univ. Press, 1959. Pp. 65-75)

10 J. Popper and R. C. Atkinson. Discrimination learning in a verbal conditioning situation. July 15, 1957. (J. exp. Psychol., 1958, 56, 21-26)

11 P. Suppes and K. Walsh. A non-linear model for the experimental measurement of utility. August 21, 1956. (Behavioral Science, 1959, 4, 204-211)

12 E. Adams and S. Messick. An axiomatization of Thurstone's successive intervals and paired comparisons scaling models. September 9, 1957. (An axiomatic formulation and generalization of successive intervals scaling, Psychometrika, 1958, 23, 355-368)

13 R. Fagot. An ordered metric model of individual choice behavior. September 12, 1957. (A model for ordered metric scaling by comparison of intervals. Psychometrika, 1959, 24, 157-168)

14 H. Royden, P. Suppes, and K. Walsh. A model for the experimental measurement of the utility of gambling. September 25, 1957. (Behavioral Science, 1959, 4, 11-18)

15 P. Suppes. Two formal models for moral principles. November 1, 1957.

16 W. K. Estes and P. Suppes. Foundations of statistical learning theory, I. The linear model for simple learning. November 20, 1957. (Foundations of linear models. In R. R. Bush and W. K. Estes (Eds.), Studies in Mathematical Learning Theory. Stanford Univ. Press, 1959. Pp. 137-179)

17 D. Davidson and J. Marshak. Experimental tests of a stochastic decision theory. July 25, 1958. (In C. W. Churchman and P. Ratoosh (Eds.), Measurement: Definition and Theories. New York: Wiley, 1959. Pp. 233-269)

18 J. Lamperti and P. Suppes. Chains of infinite order and their application to learning theory. October 15, 1958. (Pacific Journal of Mathematics, 1959, 9, 739-754)

19 P. Suppes. A linear learning model for a continuum of responses. October 18, 1958. (In R. R. Bush and W. K. Estes (Eds.), Studies in Mathematical Learning Theory. Stanford Univ. Press, 1959. Pp. 400-414)

20 P. Suppes. Measurement, empirical meaningfulness and three-valued logic. December 29, 1958. (In C. West Churchman and P. Ratoosh (Eds.), Measurement: Definition and Theories. New York: Wiley, 1959. Pp. 129-143)

21 P. Suppes and R. C. Atkinson. Markov learning models for multiperson situations, I. The theory. February 20, 1959. (Chapter 1 in Markov Learning Models for Multiperson Interaction. Stanford Univ. Press, 1960)

22 J. Lamperti and P. Suppes. Some asymptotic properties of Luce's beta learning model. April 24, 1959. (Psychometrika, 1960, 25, 233-241)

23 P. Suppes. Behavioristic foundations of utility. July 27, 1959. (Econometrica, 1961, 29, 186-202)

24 P. Suppes and F. Krasne. Application of stimulus sampling theory to situations involving social pressure. September 10, 1959. (Psychol. Rev., 1961, 68, 46-59)

25 P. Suppes. Stimulus sampling theory for a continuum of responses. September 11, 1959. (In K. Arrow, S. Karlin, and P. Suppes (Eds.), Mathematical Methods in the Social Sciences. Stanford Univ. Press, 1960. Pp. 348-365)

26 W. K. Estes and P. Suppes. Foundations of statistical learning theory, II. The stimulus sampling model. October 22, 1959.

27 P. Suppes and R. C. Atkinson. Markov learning models for multiperson situations, II. Methods of analysis. December 28, 1959. (Chapter 2 in Markov Learning Models for Multiperson Interactions. Stanford Univ. Press, 1960)

28 R. C. Atkinson. The use of models in experimental psychology. May 24, 1960. (Synthese, 1960, 12, 162-171)

29 R. C. Atkinson. A generalization of stimulus sampling theory. June 14, 1960. (Psychometrika, 1961, 26, 281-290)

30 P. Suppes and J. M. Carlsmith. Experimental analysis of a duopoly situation from the standpoint of mathematical learning theory. June 17, 1960. (International Economic Review, 1962, 3, 1-19)

31 G. Bower. Properties of the one-element model as applied to paired-associate learning. June 29, 1960. (Application of a model to paired-associate learning, Psychometrika, 1961, 26, 255-280)

32 J. H. Blau. The combining of classes condition in learning theory. August 23, 1960. (See Transformation of probabilities, Proceedings of the Amer. Math. Soc., 1961, 12, 511-518)

33 P. Suppes. A comparison of the meaning and uses of models in mathematics and the empirical sciences. August 25, 1960. (Synthese, 1960, 12, 287-301)

34 P. Suppes and J. Zinnes. Stochastic learning theories for a response continuum with non-determinate reinforcement. October 25, 1960. (Psychometrika, 1961, 26, 373-390)

35 P. Suppes and R. Ginsberg. Application of a stimulus sampling model to children's concept formation of binary numbers, with and without an overt correction response. December 14, 1960. (Application of a stimulus sampling model to children's concept formation with and without an overt correction response, Journal exp. Psychol, 1962, 63, 330-336)

(Continued on inside back cover)

Outline of a Theory of Punishment

by

W. K. Estes

Technical Report No. 123
October 1, 1967

Psychology Series

Reproduction in Whole or in Part is Permitted for
any Purpose of the United States Government

Institute for Mathematical Studies in the Social Sciences
Stanford University
Stanford, California

To appear in *Punishment and Aversive Behavior*, R. M. Church and B. A. Campbell (Eds.), Appleton-Century-Crofts, in press. Preparation of this article was supported in part by Contract Nonr 225(73) between the Office of Naval Research and Stanford University

Introduction

A rather striking characteristic of the literature on punishment is the large and still growing disparity between the volumes of theoretical and experimental contributions. For example, one finds in Boe's bibliography (this volume, Ch.) that the very greatly accelerated output of research on punishment during recent years is accompanied by no similar trend with respect to theoretical or interpretive articles. Also, in most of the major learning theories of the past few decades, treatments of punishment are either brief and casual (Guthrie, 1952; Skinner, 1938) or missing altogether (Hull, 1943; Spence, 1956; Tolman, 1932). The reason for this curious state of affairs may be in part that, whereas the interpretation of such processes as acquisition and retention is universally taken to be a primary task for learning theory, the treatment of punishment is frequently regarded as secondary, or derivative.

The concept of punishment is defined, not with respect to any unique class of events involved, but only with respect to a particular relationship of contingency. The types of stimuli used as punishers all occur in other situations as unconditioned stimuli for classical defense, escape, or avoidance conditioning. Ordinarily we speak of punishment only if stimulus which could serve as a basis for one of these types of conditioning is instead made contingent upon occurrence of some specified response. Although it is a logical possibility that punishing stimuli have some basic and unique property, for example that of reducing associative strength, which appears only when they are made contingent upon response occurrences, theories based on such an assumption have not fared well. The principal alternative view is that the effects of punishment should be entirely predictable from properties of punishing stimuli which can be determined independently in studies of conditioning which do not involve punishment contingencies. The series of experimental studies of punishment which led to my earlier monograph (Estes, 1944) seemed to call for interpretation of the latter type. While some interpretations of this type have proven viable, all, including my own first attempt, have in the course of time revealed major shortcomings.

In attempting to assimilate the factual input from the effervescence of research on punishment during the last few years, I have come to feel that converging [illegible] lines of evidence triangulate quite specifically the point at which current interpretations of punishment require revision. What I should like to accomplish in the present paper is to indicate the nature of this needed revision and to sketch in outline how it leads to my own second approximation to a theory of punishment.

By way of general organization, I propose firstly to review the main experimental facts leading to my 1944 interpretation; secondly, to evaluate and criticize that formulation in the light both of facts available at the time and of others which have come to hand subsequently; thirdly, to offer a revised interpretation; and finally, to make at least a start on the job of assaying the merits of my second approximation for handling the much larger body of data now available.

BLANK PAGE

I. Empirical Context of Original Formulation

Like most psychologists of my generation I was educated on an interpretation of punishment growing out of Thorndike's development of the law of effect. However, I was not at all comfortable with the asymmetry of Thorndike's later formulation, which held that rewards have a direct positive effect on strength of the preceding response whereas punishments act only indirectly by somehow increasing variability of behavior (Thorndike, 1931, 1935). My dissatisfaction arose from both theoretical and empirical considerations. On the one hand, it was hard to see why qualitatively different mechanisms should have evolved to mediate the influences of the two kinds of after effects on learning; on the other, the various stages of development and modification of the law of effect as it pertains to punishment were based almost exclusively on studies using punishments which involved little or no element of pain or trauma, usually merely indications of incorrectness of response. The one published study of punishment in an operant situation prior to 1940, that of Skinner (1938), yielded results in seeming agreement with Thorndike's conclusions, but also involved only very mild punishment.

Thus my own series of studies on punishment, leading to the 1944 monograph, was initiated with a view to seeing whether more severe punishments would not yield effects comparable in uniformity and magnitude to those of rewards. These experiments were unequivocal in showing that a more traumatic stimulus, electric shock, administered immediately consequent upon bar pressing responses by rats, yielded reliable and uniform suppression of responding, the degree and duration of suppression being directly related to the intensity of the shock and the duration of the period of punishment. These results, which have been replicated many times by other investigators, led me to feel that I might have been wrong and that the effect of punishment was simply the opposite of that of reward, namely to exert a direct weakening effect on the strength of the punished response.

Just one bit of evidence from these studies did not quite jibe with this conclusion and ultimately led to my principal series of studies on punishment. In all respects but one the effects of punishment seemed to be simply an amplification of the usual effects of non-reward on a previously food rewarded response. The exception had to do with recovery from punishment. If, following training of a response with food reinforcement, a series of sessions of extinction is given, frequency of responding simply declines in regular fashion from one session to the next as seen, for example, in the control curve of Figure 1. If, however, responses during the first extinction period are punished, then, under some conditions, the curve of response frequency per period does not decline regularly during subsequent sessions of unpunished extinction but rather exhibits recovery, sometimes rejoining the control curve at some point, as in the case of the lower experimental curve in Figure 1, and sometimes exceeding it (compensatory recovery) as in the case of the upper experimental curve in Figure 1. This figure is based on data from Experiment F of my 1944 monograph. The essentials of the experiment are that the control group and one experimental group

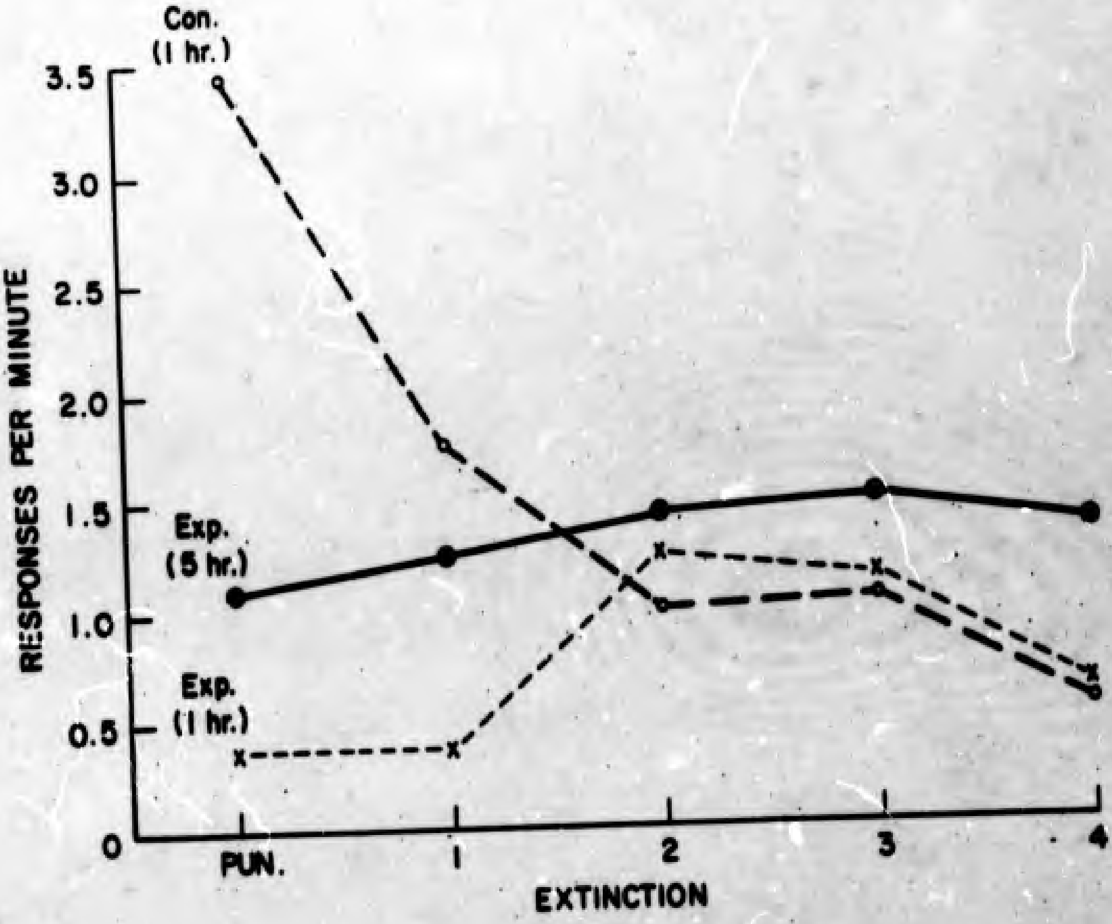

Figure 1. -- Suppressive effect of a period of punishment (Pun.) upon subsequent extinction responding, in relation to number of hours of previous training under partial reinforcement.

received one hour of four-minute, fixed-interval food reinforcement for bar pressing after initial conditioning and the other experimental group five hours; then all groups received a forty-minute period of extinction during which both experimental groups were punished with shock for all responses; finally, on four consecutive days all groups received one hour periods of extinction.

Aside from the partial recovery from the effects of punishment, another feature of this result bears emphasis, namely the fact that resistance to the effects of punishment varies directly with the amount of previous training. This relationship has been somewhat obscured by later studies which have shown in some instances that resistance to punishment is essentially unaffected by different amounts of training under conditions of 100% reinforcement. I do not know of any results in the literature, however, which throw any doubt on the generalization that resistance to punishment is an increasing function of the amount of training when training is given with intermittent reinforcement.

The findings concerning recovery suggested strongly that punishment must involve a process distinct from simple extinction and following a different time course. If punishment and extinction were two alternative conditions yielding the common result of weakening response strength (so that the addition of punishment simply accelerated the course of extinction), then the curves for the experimental groups should have continued to decline following the period of punishment and, in particular, should never have crossed the control curve. One parsimonious interpretation can be formulated in terms of stimulus generalization effects. Since the introduction of punishment involves a novel stimulus, electric shock, which was not present during acquisition, the shift from punishment plus extinction to simple extinction returns the organism from a stimulus situation differing drastically from that of acquisition to one more similar to that of acquisition. However, this hypothesis would imply a greater relative recovery effect following more intense punishment. Another superficially plausible interpretation involves the effects of changes in relative reward value of the outcomes of responses. Presumably the combination of punishment and absence of food reward would be the outcome of lowest reward value; thus a shift from punishment plus extinction to simple extinction would involve an increase in rate of responding. As in the case of the generalization hypothesis, however, this interpretation would imply greater relative recovery following more severe punishment, which is certainly contrary to fact.

A more promising interpretation was suggested by some independent sources of evidence which came to hand at just about the time of the studies of punishment and recovery. I refer to the initial experiments on the establishment of the conditioned emotional response (CER) (Estes & Skinner, 1941) which showed that a stimulus which precedes a noncontingent shock acquires the capacity of suppressing ongoing behavior. In view of this finding, it appeared that the effects of punishment must be due at least in part to the establishment of a CER to cues which were normally part of the discriminative stimulus complex for the response, and thus necessarily paired with shock on punishment trials.

Two major testable implications of this assumption came immediately to mind. The first was that it should be possible to mimic the effects of punishment to some extent simply by giving periodic electric shocks, uncorrelated with the animal's behavior, during a period when it was engaged in responding for food reward. Experiments of this type were done and the results were generally confirmatory, the effects of non-contingent shocks being to generate a suppression of operant behavior with time courses of suppression and recovery generally similar to those of response contingent punishment. More importantly, it should be possible following a period of response contingent punishment to accelerate greatly the course of recovery by giving a period of adaptation in the apparatus with the manipulandum for the operant response removed but with opportunity for extinction of the CER to other cues normally a part of the discriminative stimulus complex for the response. Results of experiments of this type are exemplified by the one portrayed in Figure 2 (from Experiment J of my 1944 monograph). Following training on four-minute fixed interval food reward for bar pressing, both groups were given a ten-minute period of response-contingent punishment for all responses, reward being discontinued; then the adaptation group was placed in the boxes with the levers removed for two one hour periods in order to permit extinction of the CER to cues of the experimental situation, the no adaptation group not being exposed to the apparatus during these periods. During the subsequent six hourly periods of simple extinction, recovery from the effects of punishment was very greatly accelerated in the case of the adaptation group, providing rather cogent support for the idea that at least a major portion of the normal effect of punishment may be accounted for in terms of the establishment of a CER.

II. First Approximation to a Theory of Punishment

The set of results just described, together with those of the classical experiments already in the literature concerning effects of delay of punishment and the like, all seemed to point to an interpretation in terms of a theory which assumes the primary mechanism in punishment to be the establishment of a CER. Upon an occurrence of punishment of a response, the punishing stimulus provides a basis for establishing a CER to any cues immediately preceding the evocation of the punished response, such as experimentally controlled discriminative stimuli, cues associated with the manipulandum involved, and to a lesser extent general background stimuli. Then on subsequent occasions, when the animal is exposed to these same cues, the CER will be evoked, leading to suppression of ongoing operant behavior, including, in particular, the previously punished response. The differences between effects of response contingent and noncontingent punishment would be interpreted simply as a matter of differential opportunities for establishing a CER to cues closely associated with occurrence of the punished response, -- in the case of lever pressing, cues associated with the lever and the movement of the lever itself.

This mechanism by itself would appear to account for the usual suppressive effects of punishment and their functional relationships

BLANK PAGE

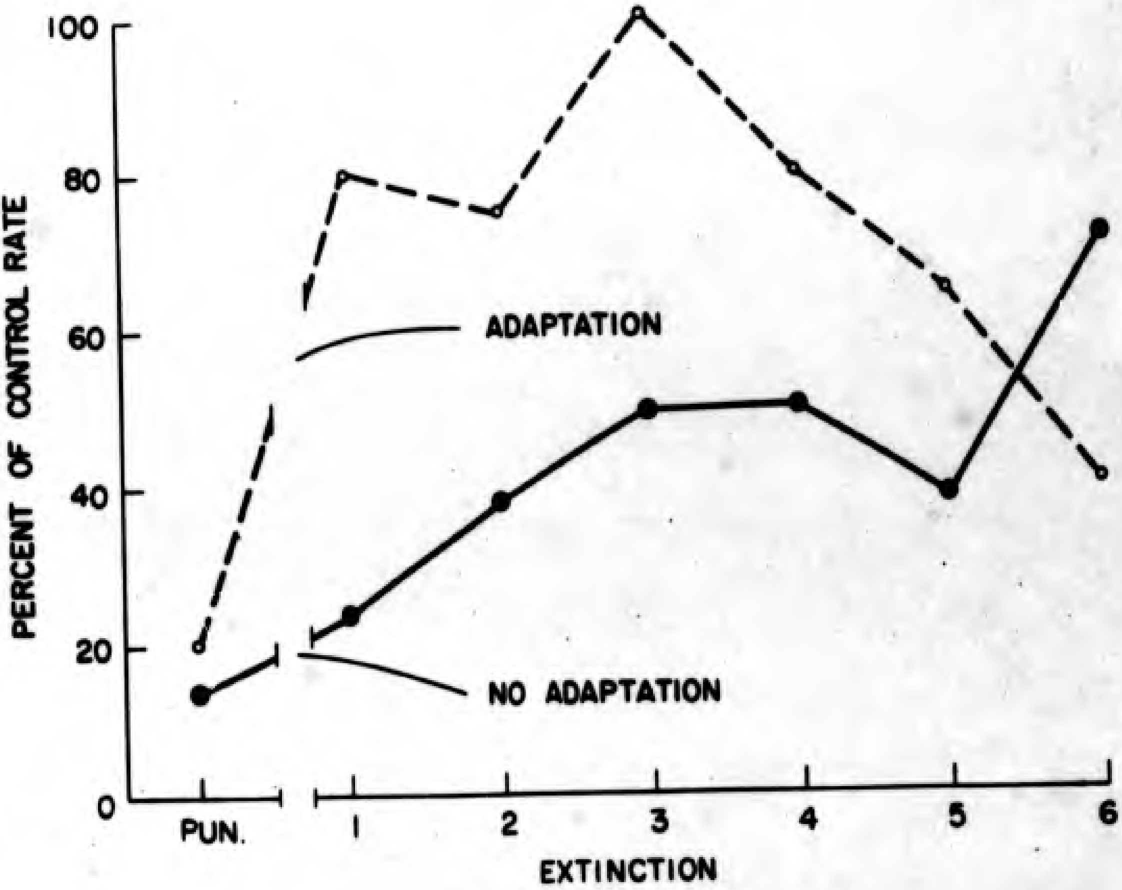

Figure 2. -- Recovery from effects of punishment of a previously rewarded response in relation to opportunity for adaptation to apparatus cues between the period of punishment and the first period of extinction.

to intensity of the punishing stimulus, duration of period of punishment, delay of punishment, and differences between contingent and noncontingent punishing stimuli. Further, it allows for different rates of recovery following different amounts of punishment and also for the acceleration of recovery by adaptation to stimuli in the experimental situations during a period when the punished response is prevented from occurring.

The principal limitation of the CER interpretation, relative to the facts available at the time of its formulation, was the difficulty of accounting for instances in which recovery from effects of punishment could evidently be delayed indefinitely by a prolonged period of severe punishment. What seemed to me at that time the most parsimonious augmentation of the theory to handle this observation was to assume that with adequate opportunity a withdrawal response, incompatible with execution of the punished response, might become conditioned to the cues previously leading to the former; that is the organism would establish a conditioned avoidance response (CAR).

III. Evaluation of the CER-CAR Theory

The two factors, CER and CAR, in varying combination, seem to characterize most interpretations of punishment espoused by other investigators down to the present. Both are prominent, for example, in the major recent reviews of the field by Church (1963), and by Solomon (1964). The most popular version seems to be a two-stage combination: The first instances of punishment lead by classical conditioning to establishment of a CER; then some response which terminates the conditioned stimuli for the CER, or removes the animal from them, is reinforced by this termination (reduction of fear or anxiety). The instrumental avoidance response thus established being in direct competition with punished response, results in its suppression. Different versions of this interpretation have been presented by Dinsmoor (1954), though in somewhat different terms, and Solomon (1964), among others.

The CAR component of the dual process interpretation has proven, in my estimation, to be the weak link. Firstly, the notion that suppression of a response by punishment is primarily the result of its displacement by a competing avoidance response was never founded in direct observation of the supposed process of avoidance conditioning. Secondly, the uniformity with which a response is suppressed by punishment of sufficient intensity does not jibe with the extreme difficulty observed in many situations in establishing avoidance responses with similar shocks as unconditioned stimuli. Further, the time courses of the two classes of phenomena are not at all similar. Only under a very few special circumstances does one ever observe rates of avoidance conditioning comparable to the rates at which suppressive effects of punishment appear under a wide range of conditions. Finally, the effects of the same punishing stimulus are often observed to be quite different depending upon whether the punished response has been maintained by a positive reward, such as food, or by escape or avoidance. Frequently responses previously reinforced on an avoidance schedule are not suppressed by punishment and may even be facilitated. All this is not to say that in some situations involving punishment active avoidance responses may not ultimately be established. However, the weight of the evidence seems to me to indicate that the conditioning of active avoidance responses cannot be a necessary condition for suppression of a response by punishment, and further, that probably the immediate suppression of ongoing behavior by punishment is a facilitating, if not necessary, condition for the establishment of active avoidance responses in the same situation.

The notion of suppression of ongoing behavior by a CER consequent upon the occurrence of punishment seems descriptively sound so far as it goes. The conditions under which prompt and uniform suppression of responding by punishment occurs are precisely those known to be favorable for establishment of a CER. However, there is a basic conceptual weakness: Namely, it has never been spelled out in detail why and how a CER suppresses ongoing behavior. Most investigators in this area have been content to note that the animal "freezes" upon occurrence of a stimulus which has preceded shock. However, the notion of freezing simply describes a behavioral phenomenon without elucidating the process or mechanism involved.

My own original assumption, though not spelled out either in the Estes & Skinner (1941) article or in my 1944 monograph was that a CER exerts its effects on ongoing behavior essentially via stimulus generalization decrement. A stimulus which precedes shock will become a CS for a variety of visceral and skeletal reactions all carrying characteristic interoceptive and perhaps also proprioceptive stimuli. Then upon the occurrence of that CS in an operant situation, this barrage of stimuli, novel to that situation, will suddenly be elicited and, simply by changing the stimulus conditions under which the operant behavior has been learned, will lead to a decrement in response rate.

In hindsight I can see three major weaknesses in this interpretation. Firstly, as in the case of the avoidance interpretation, independent evidence for the assumed process has not been forthcoming. Secondly, the time course of suppression of behavior by a CER or by punishment does not prove similar to the time course of a disturbance of behavior by simple extraneous stimulation. In the case of the latter, the maximum effect is always manifest upon the very first trial in which the extraneous stimuli are introduced, with a monotone course of recovery as the new stimuli become conditioned under the continuing reinforcing schedule. Contrariwise, the effects of punishment generally increase with repetitions and, if the stimulus is of sufficient intensity, no recovery is observed so long as punishment is continued. Thirdly, the effects of CER have turned out to depend upon the nature of the baseline behavior, the stimulus for the CER suppressing ongoing behavior if it has been maintained on a positive reward schedule but facilitating ongoing behavior if it has been maintained on an avoidance schedule (Herrnstein & Sidman, 1948; Waller & Waller, 1963). This last result could be brought into harmony with a generalization decrement hypothesis by means of some plausible additional assumptions, but I think it may be better simply to take it as a straw in the wind pointing toward a more satisfactory interpretation of a somewhat different character.

IV. Second Approximation to a Theory of Punishment

In order to simplify the following exposition, I shall begin with a few demurrers, for the theory to be outlined is not intended to be complete enough to provide a full and detailed interpretation of a wide range of experiments on punishment. Firstly, the conditioning of active avoidance responses in punishment situations is not an integral part of my interpretation; however, this is not to deny that such conditioning may occur. When conditions are such as to facilitate establishment of a CAR, the effects of punishment will naturally be prolonged, but I believe it possible to account for the main facts about punishment without appeal to the learning of competing responses. Secondly let us understand that, as Church has brough out nicely in his 1963 review, the punishing stimulus has properties of stimuli in general as well as those peculiar to its class, and, further, that in most situations punishing stimuli will have greater weight than ordinary background cues or discriminative stimuli. The notion of "weight" may be equated roughly with "attention value" or, in the context of stimulus sampling theory, the number of associated stimulus elements. (The ideas involved are precisely those that I have previously developed in connection with drive stimuli [Estes, 1958]). Thus, the interpretation to be sketched in the sequel will be limited to the primary process believed to mediate the distinctive effects of punishment which cannot be accounted for simply by the effects of the punishing stimulus per se.

In the light of the ensuing quarter century of research, I believe now that I was right back in the early 1940's, both in assuming that the effects of reward and punishment should be essentially symmetrical, and also in concluding that interpretation of punishment requires a separate process rather than a simple weakening of associative strength. I think that where I went wrong, in the illustrious company of Thorndike, Skinner, and Hull, among others, was in assuming the effects of reward to involve a simple, direct strengthening of associative connections, and thus in looking for the wrong kind of symmetry. What I wish now to outline is a dual process interpretation of both reward and punishment, with an associative process common to both but with reward and punishment each involving separate, though symmetrical, effects upon performance.

Unfortunately for convenience of exposition, the organism's behavior is not so compartmentalized that one can present a theory of punishment without reference to other processes having to do with discrimination, drive, and reward, among others. As a compromise for our present purposes, I shall begin by sketching some modifications in the general statistical. theory of learning presented in earlier papers (e.g., Estes, 1950, 1959) that seem to be called for by new sources of evidence on reward and punishment and then shall indicate how some of the principal phenomena of punishment can be treated within the new framework.

A convenient point of departure is my paper concerned with the stimulus sampling interpretation of drive (Estes, 1958). The primary assumption was that the organism's behavior at any time is jointly controlled by stimuli of external origin, discriminative stimuli or cues, and by stimuli of internal origin, drive stimuli. At any moment the stimulus population available for sampling by the organism was assumed to comprise elements of both types, the number of cue elements being a function of such experimental manipulations as the presentation of discriminative stimuli and the number of drive elements being a function of such variables as deprivation time. Any individual stimulus element of either type was assumed to be associated with (or, "connected to") exactly one response at any given time and the probability of a response was assumed to be equal to the proportion of the elements currently sampled, regardless of origin, associated with the given response. That is, cues and drive stimulus elements were assumed to be strictly interchangeable and to combine additively in their effects on behavior. Further, the determination of response probability by the stimulus sample was assumed to be exhaustive. That is, given the makeup of the stimulus sample, response probability was fully specified; variables having to do with drive or motivation could influence behavior only insofar as they might control the set of stimuli in the current sample.

Within that framework, there were basically only two ways in which punishment could modify behavior: (1) by directly changing the state of conditioning of stimulus elements previously associated with the punished response; or (2) by evoking behaviors incompatible with the punished response under conditions conducive to counter-conditioning. But the many lines of accumulating evidence briefly surveyed above have convinced me that the former of these conceptions is incorrect and the latter insufficient. Rather, it appears that the effects of punishment must primarily be exerted via the weakening of motivational support for the punished response in a manner not provided for by earlier associationistic theories.

I now propose to replace the assumption of simple, additive stimulus-response connections with what may be termed a summation or stimulus amplifier, hypothesis. In the reformulation, it will be assumed that the occurrence of response requires a summation of input from stimulus and drive sources. Regarding the latter, the primary function of drives and rewards is to act as, so to speak, stimulus amplifiers. Except perhaps in the case of certain reflexes, response evocation requires that the stimuli associated with the given response as a result of previous learning or innate organization summate with internally generated <u>amplifier</u> <u>elements</u>. It would be natural to refer to these as "drive elements" but a new term without so many associations may help avoid confusion with the closely related conception of ordinary discriminative elements which arise from drive-related operations such as eating and fasting.

The principal addition to the structure of earlier stimulus sampling theory is that of a source, or generator, of amplifier elements associated with each of the principal drive systems, e.g., hunger, thirst, pain. It will be assumed that each of these generating sources provides a certain base rate of input of amplifier elements under a given deprivational or stimulating condition and that local changes in the input are evoked by the occurrence of traumatic stimuli,

BLANK PAGE

stimuli for consummatory behaviors, and the like.

Although the precise form of quantification is not of central importance for our present purposes, the response evocation process conceived in the new theory may be most easily clarified by comparing it with that of earlier versions of stimulus sampling theory. In the former (see, e.g., Estes, 1959; LaBerge, 1959) it is assumed that on any trial of a learning experiment the organism draws ("perceives") a sample of the available discriminative cues, some of which may be connected to the reference response as a result of preceding learning, some to competing responses, and perhaps some to neither. Elements which are not connected either to the reference response or to alternative competing responses which may occur in the given situation are customarily termed "neutral" elements (LaBerge, 1959). Having drawn a sample of elements, the organism scans these singly, the scanning continuing until an element is processed which is connected with a permissible response, and then that response is made overtly. Thus, response latency depends upon the density of neutral elements in the sample, and the probability of a given reference response is equal to the proportion of nonneutral elements in the sample which are connected with that response.

In the revised theory, the sampling and scanning processes are assumed to proceed in the same way, but with one major qualification. Namely, when a nonneutral element in the stimulus sample is processed, it will evoke a response only if an amplifier element is sampled simultaneously. Under any given drive-reward condition there is some probability that any given element in the sample will be processed simultaneously with an amplifier element. The latency of the evoked response will vary inversely with this probability, but the probability of a given reference response relative to competing responses will be unaffected. However, as will be developed in more detail in the sequel, different stimuli in an experimental situation may, as a result either of innate organization or of learning, have different probabilities of being accompanied by amplifier inputs; thus, in effect, the stimuli will have different weights in response determination.

The way in which amplifier elements enter into learning can be elucidated in terms of one of the positive drive systems, say that associated with hunger, and a negative system, say that associated with pain. It will be assumed that prior to any learning experiences the amplifier input of a given system is connected to a family of stimulus-response units, those having to do with consummatory behavior in the case of hunger, those having to do with escape, attack, and other defensive behaviors in the case of pain. When for example, an animal becomes hungry, the base rate of input of amplifier elements to the appropriate family of responses increases; this in itself does not lead to overt response occurrences, but it provides a basis for summation of amplifier elements with any unconditioned or conditioned stimuli for consummatory responses which may become available.

Although we cannot go into detail in this paper, it may be seen that the proposed mechanism for combining effects of discriminative and drive inputs will account in a natural way for a number of phenomena which have been awkward to handle in the earlier theory. One of these is the commonly observed disparity between the strong control of rate and speed of responding in simple operant situations by deprivation conditions and the difficulty of developing discriminations based upon different deprivation conditions. The former relation results, in the present model, from the direct relationship between input of drive amplifier elements and the probability that currently available discriminative cues will receive the summation necessary to lead to response evocation. The difficulty of discrimination arises from the fact that, although the amplifier inputs associated with two drive conditions, say hunger and thirst, may be quite distinct they do not by themselves evoke overt responses, and the populations of interoceptive or proprioceptive cues associated with different deprivations have high proportions of element in common. Secondly, the covariation in strength, or probability of occurrence, of families of responses as a function of such operations as deprivation is more readily handled in the revised theory, since it is no longer assumed that any particular amplifier element can be associated with only one response at a given time. Thirdly, the dissociation between thresholds determined electrophysiologically and thresholds determined by behavioral preference tests fits naturally into the present schema. For example, adrenalectomized rats show a markedly reduced threshold for salt in preference tests but no difference from normals in electrophysiological determinations (Pfaffmann & Bare, 1950); in the present terms, the result of adrenalectomy is to increase the input of amplifier elements to a consummatory response system involved in the ingestion of salt solutions. while the sampling probabilities of gustatory stimuli are unaffected.

The two additional revised assumptions of greatest import have to do with reciprocal inhibition and with conditioning. Regarding the former, it is assumed that the activity of the negative, flight-attack system results in reciprocal inhibition of the activity of generators belonging to positive drive systems. Thus, whereas in many extant theories (including Thorndike's formulation of the law of effect, 1931; Guthrie's contiguity theory, 1952; previously published accounts of statistical learning theory, as Estes, 1959; and perhaps also Hull's theory, 1943, 1952) an account of the suppression of positively motivated behavior by punishment must involve appeal to competing responses, in the present theory the immediate effect of punishment is to reduce the supply of amplifier elements needed for maintenance of the positively motivated behavior. This I am inclined to regard as a considerable advantage in view of the long history of meagre success on the part of many investigators in attempting to pin down the specific competing responses evoked by various punishing stimuli.

The assumed conditioning process needs to be spelled out in some detail since it differs somewhat from that embodied in my own earlier theory and, to the best of my understanding, from those of other extant learning theories. Considering first a positive system, such as that involved in hunger and food ingestion, the generation of amplifier elements is assumed to be jointly controlled by deprivation conditions, which by themselves provide a relatively steady base rate of amplifier input, and by stimuli, gustatory in this instance, which initiate consummatory behavior. Occurrence of the latter yields a momentary increase in amplifier input, which in turn provides a basis for summation and thus facilitation of subsequent components of the chain of consummatory responses. Through conditioning by contiguity, the capacity of certain stimuli to evoke changes in drive input is transferred to other stimuli which immediately precede them; over a series of occasions the facilitatory effects move backward, that is begin to occur anticipatorily. At a later stage in the conditioning process, cues which occurred prior to those evoking the rewarded response will generate an input of amplifier elements facilitating approach to the latter, and so on. Thus, after establishment of the behavior chain leading to reward, the first member occurs when the organism is exposed to the appropriate discriminative stimulus and this summates with amplifier elements generated by the existing deprivation condition to evoke the first response of the chain. The feedback consequence of this response is to generate an increase in amplifier input which provides a basis for summation, and thus facilitates occurrence of the behaviors which follow in the chain.

In the case of a negative system, say that associated with an electric shock stimulus, the generation of amplifier elements is originally controlled only by the painful stimulation itself, the consequence of this input being to provide a basis for summation and thus to facilitate the occurrence of members of the flight-attack family of behaviors which might occur in the presence of the shock. As a result of conditioning by contiguity, this control of what may be termed negative amplifier input is transferred from the shock to stimuli immediately preceding it. The anticipatory occurrence of the negative input entails facilitation of the family of initial responses to shock and at the same time inhibition of the activity of any positive drive systems which might have been controlling the organism's behavior just prior to the shock.

Thus the consequences of variations in drive input are quite different in the two types of situations. When the hungry animal tastes food, the result is a generation of facilitative feedback that locks the animal in on the stimulus which initiated the consummatory activity and helps insure that the chain of consummatory behavior will run to completion. When the animal makes a response which brings it into contact with a painful stimulus, the result is the generation of feedback which increases the probability that the organism will break contact with the painful stimulus.

It should be noted that conditioning can occur between as well as within positive and negative drive systems. Thus, if a shock is followed by food, the result will be that the increase in amplifier input to consummatory behaviors normally following food intake will come to be evoked by the shock as a conditioned stimulus, attenuating the normally negative effects of the shock. Conditioning will occur, of course, only if shock is not so intense as to inhibit entirely the normally positive response to food which follows. Conversely, if food precedes shock, the negative drive input evoked by shock will come to be evoked by stimulation from food or cues which preceded it, thus leading on subsequent occasions to inhibition of the facilitative support for the hunger motivated behavior which initially led to approaching and ingesting food. A qualitative implication of this assumed conditioning process is that if a response is followed by both reward and punishment, say food and shock, and the shock is not so severe as to inhibit hunger motivated behavior entirely, the animal should learn to delay the ingestion of food until after the shock occurs.

V. Interpretations of CER and Punishment in the Revised Theory

In order to give a full account of experiments involving punishment it would be necessary to discuss the representation of acquisition and extinction within the revised stimulus sampling theory in more detail than is feasible in the present paper. Thus in order to bring out some of the distinctive implications of the new theory for phenomena of punishment, specifically, let us simply assume an experimental situation in which a positively motivated operant response has been established and is occurring at some stable rate under the joint control of discriminative stimuli and deprivation-produced amplifier input. If, now, the organism is subjected to the usual CER conditioning procedure in a different situation, an originally neutral CS being presented and followed by a noncontingent shock, conditioning will occur such that after this training the CS will evoke the negative amplifier input originally produced by the shock. When, now, the CS is tested in the operant situation, the consequent generation of negative elements will have two effects. Firstly, via the summation process assumed in the theory, the probability of occurrence of responses belonging to the flight-attack family will be increased. Secondly, regardless of whether any specific overt responses occur which would be incompatible with the ongoing operant behavior, the increase in activity of the negative drive system will reciprocally inhibit the positive system which had provided facilitation for the positively motivated operant response, thus producing a decrease in probability of the latter. The degree of response suppression will be a joint function of the intensity of the shock and the prevailing level of positive drive input.

An aspect of the CER experiment which has generally escaped explicit comment needs discussion in view of the recent study by Rescorla (1968), who has demonstrated the importance of the discriminative contingencies involved. During CER training a CS is followed by shock, and after conditioning has occurred negative drive activity is increased during both CS and shock presentations with the consequent inhibition of positive amplifier input. However, termination of the CS and shock are in consequence uniformly followed by a decrease in negative input, with the resulting elimination of the reciprocal inhibition and an increase in positive amplifier input to the prevailing level. Thus termination of the CS and shock become a conditioned signal for increase in the positive input, and over a series of occasions the suppression of behavior by the CS becomes progressively more sharply confined to the period during which the CS and shock are present. If, on the contrary, training were entirely nondiscriminative, that is shocks simply being given intermittently in the experimental situation without a preceding signal, then the activity of the negative amplifier system would become conditioned to a variety of cues in the experimental situation, all of which would come to have suppressive effects; on the other hand no stimuli would be uniformly correlated with shock termination and the recovery of positive input. The result to be expected in this case would be a diffuse suppression of responding throughout the experimental session.

As in the earlier theory, the primary mechanism of punishment is assumed to be the establishment of a CER, the role of the CS being taken on by cues which originally led to the occurrence of the punished response and thus were temporally contiguous with the onset of the punishing stimulus and its attendant increase in negative drive input. In this interpretation the well known importance of temporal contiguity between response and punishment is simply a corollary; the critical relation is that between the cues originally initiating the punished response and the onset of the punishing stimulus. Experimental arrangements which insure that the punishing stimulus will follow closely upon the response also improve the temporal contiguity between the punishing stimulus and the discriminative cues.

As soon as conditioning has occurred, so that cues originally leading to a punished response have taken on the function of a CS for a CER, the occurrence of these cues will lead to an increase in negative amplifier activity. During presentation of this CS, the organism will suffer inhibition of the positive input which must be available to summate with discriminative stimulation in order to evoke the response. Whereas effects of noncontingent shocks may be expected to be eliminated entirely during a period of adaptation to the experimental situation without shock, when conditioned associations between various apparatus cues and negative amplifier activity can extinguish, recovery will generally be incomplete during a similar period of adaptation following response contingent punishment. In the latter case, not all of the cues involved in the initiation of the response will be present during the adaptation period, so that the CER will be protected from complete extinction. For example in the studies of this type that I reported earlier (Estes, 1944) the punished response was bar pressing and the adaptation period involved exposure to the apparatus with the bar removed. During this period the animals might explore the vicinity of the bar and make some of the movements normally involved in approaching it, but could not expose themselves to all of the stimulation previously entailed in bar pressing.

Unlike the earlier theory, the new formulation predicts quite different effects if CER or punishment procedures are imposed on a baseline of negatively rather than positively motivated behavior. Suppose, for example, that a CER is established in the usual way but that the effects of the CS are then tested during a period when the animal is operating a response manipulandum in order to escape shock rather than in order to obtain food. In this case, the increase in negative amplifier input during the period of the CS will add to rather than subtract from the level of facilitative input supporting the response. Although just as in the case of a hunger motivated response, the CS for the CER will lead to inhibition of any prevailing positive drive input, the only relevant effect of this will be to reduce further the probability of occurrence of positively motivated responses which might otherwise occur in this situation in competition with the escape response.

The effects of response contingent punishment of an escape response are too complex to be handled in any general way at a qualitative level. It is clear that the suppressive effects of punishment would be less than for an otherwise comparable positively motivated response and that the degree of suppression would depend on the relative intensities of the stimulus being escaped and the punishing stimulus. Specification of the functional relationships involved and of the conditions under which facilitation rather than suppression of the punished response might be expected (as observed in studies of "vicious circle" behavior by Brown, 1964; Martin, et al. 1964) must wait upon further examination of the new theory by mathematical or computer simulation methods.

Similarly the effects of shock for correct responses in discrimination learning (Muenzinger, 1934; Fowler & Wischner, 1968) depend upon a balance of parameter values and cannot be satisfactorily analyzed at a qualitative level. If the shock is sufficiently intense, so that its effects persist into the subsequent consummatory activity and reduce the positive drive stimulus input that would normally occur, then the probability of the correct response would necessarily be reduced as compared to an otherwise similar case in which correct responses were not followed by shock. However, if the intensity of the shock were lowered sufficiently and its effects did not diminish the positive input associated with subsequent ingestive behavior, then the shock would become a CS for activity of the positive system. The net result in this instance would be amplification of the effects of discriminative cues associated with the correct choice and a consequent improvement in performance.

Phenomena having to do with recovery from effects of punishment are of special interest in relation to alternative theories. Although, again, detailed account of the implications of the present formulation cannot be given without mathematical analysis, some major qualitative predictions can be indicated and the importance of a major distinction between two types of experimental situations elucidated by means of the illustrative curves presented in Figures 3 and 4. Although the curves were derived from a quantitative formulation of the ideas presented in this paper, the curves can be understood without reference to the derivations. Let us consider first an experiment conducted with discrete trials, for example a runway experiment in which each trial terminates with the occurrence of the reference response. If, following a period of positively rewarded training, simple extinction is initiated, the probability of the previously rewarded response should decline along a negatively accelerated curve of the form indicated for the control condition in Figure 3. The associative relationship previously established between discriminative cues for the response and stimuli for consummatory behavior extinguishes over the sequence of trials when reward no longer follows the response; and, as the organism's tendency to anticipate positive amplifier activity following a response decreases; so also does the input of positive elements needed to facilitate response occurrence. If, during the initial portion of the extinction series each response is punished, then, as indicated in the upper panels of Figure 3, the animal learns to anticipate shock following response

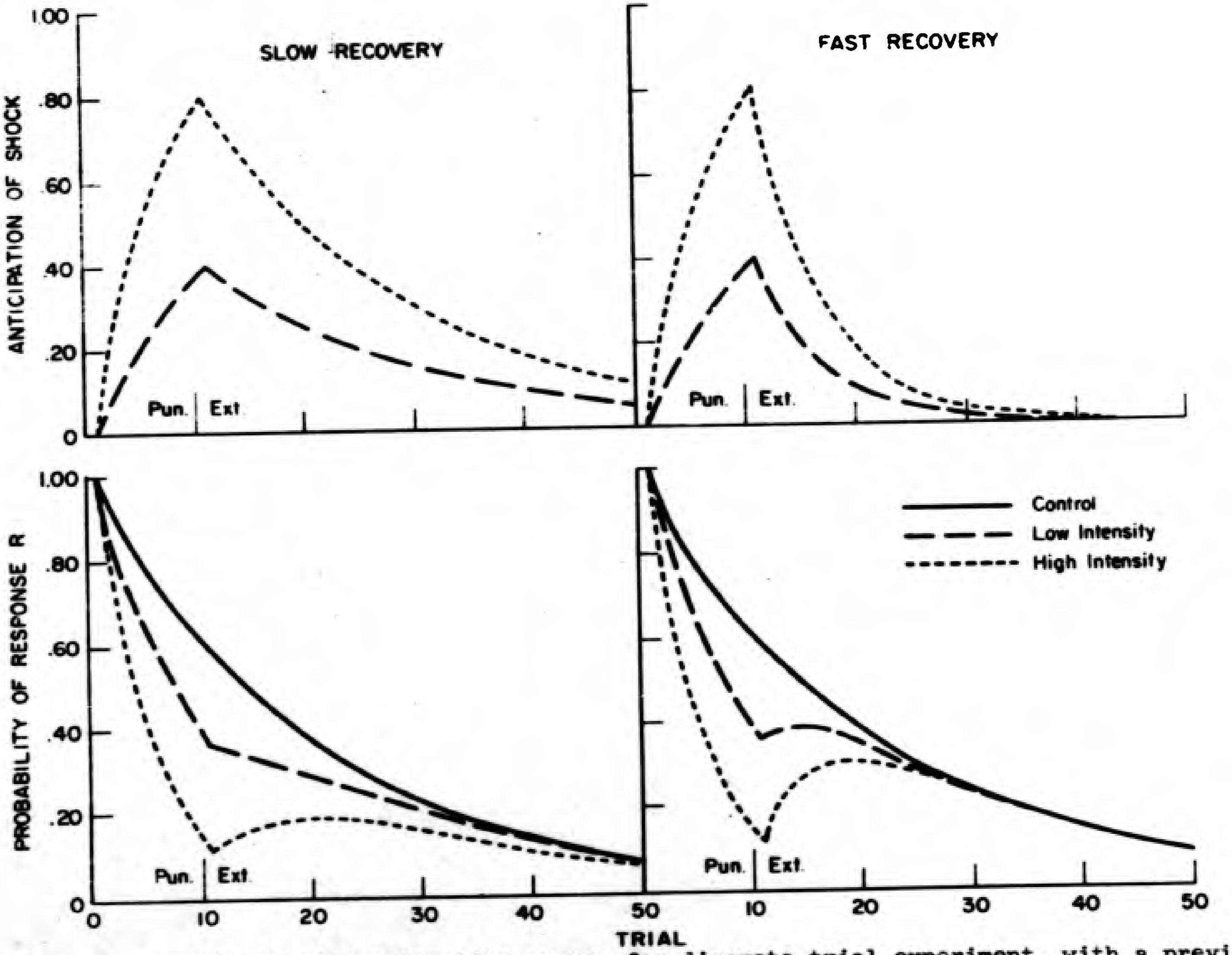

Figure 3. -- Illustrative extinction curves for discrete trial experiment, with a previously rewarded response (R) receiving 10 trials of punishment by electric shock followed by simple extinction. Upper panels show the acquisition and extinction of anticipation of shock; lower panels, changes in probability of R during punishment and extinction (extinction throughout for the control condition). The two punishment conditions in each panel represent different intensities of the punishing stimulus. The left and right sides of the figure differ only with respect to the parameter governing rate of extinction of shock-anticipation following discontinuation of punishment.

occurrences. Conditioning of the tendency to anticipate shock follows a negatively accelerated course at a rate which is directly related to intensity of the punishing stimulus. The immediate consequence of this learning is that negative amplifier activity comes to be evoked by the cues which formerly led to the punished response, reducing the level of facilitative support for the response, and thus its probability of occurrence, below that of the control group. The value of response probability on any trial n for a given punishment curve in Figure 3 is obtained by multiplying the value of the control curve on trial n by $1-a_n$, where a_n denotes the value of the corresponding anticipation of shock function in the upper panel.

If at some point, following trial 10 in the example, punishment is discontinued, then the tendency to anticipate shock also undergoes extinction as shown in the right-hand side of each of the upper panels of the figure. As this extinction lowers the activity of the negative system which inhibited the positive input during the period of punishment, the input of positive elements again becomes available and the curves of response probabilities for the punished animals approach those of the controls, as shown in the right-hand side of each of the lower panels. The general qualitative predictions for this situation are that, following the discontinuation of punishment, recovery will occur but that the rate and extent of recovery will be a function of the intensity of punishment. Further, recovery will be delayed according as experimental conditions during punishment (e.g., intermittency of shock) favor resistance to extinction of the anticipation of the punishment. The left and right panels of Figure 3 differ only with respect to the parameter governing rate of extinction of shock anticipation (decrease in a_n) following the termination of punishment. Conversely, recovery will be accelerated according as previous conditions of reinforcement favor resistance to extinction of the punished response. It should be noted, in particular, that for the discrete trial situation, with the assumption that each trial continues until the reference response occurs, there can never be compensatory recovery, that is recovery which would carry the curves for the previously punished animals above the curve for the control condition.

A comparable analysis is presented in Figure 4 for a typical free responding operant situation in which probability of the reference response is recorded as a function of time in the experimental situation (all parameter values being the same as those of the corresponding curves of Figure 3). The course of conditioning of anticipation of shock and the effects of this upon response probability are essentially the same as in the discrete trial case. The important differences appear following the discontinuation of punishment. The predictions of the theory* are that, as illustrated in the figure, for the same parameters of reward and punishment, recovery will in general be delayed longer following the termination of punishment in the free responding situation, but on the other hand compensatory recovery may occur, with

*Derivations are more difficult than in the discrete trial case, and the illustrative curves of Figure 4 were obtained by computer simulated runs of groups of 100 "statistical subjects."

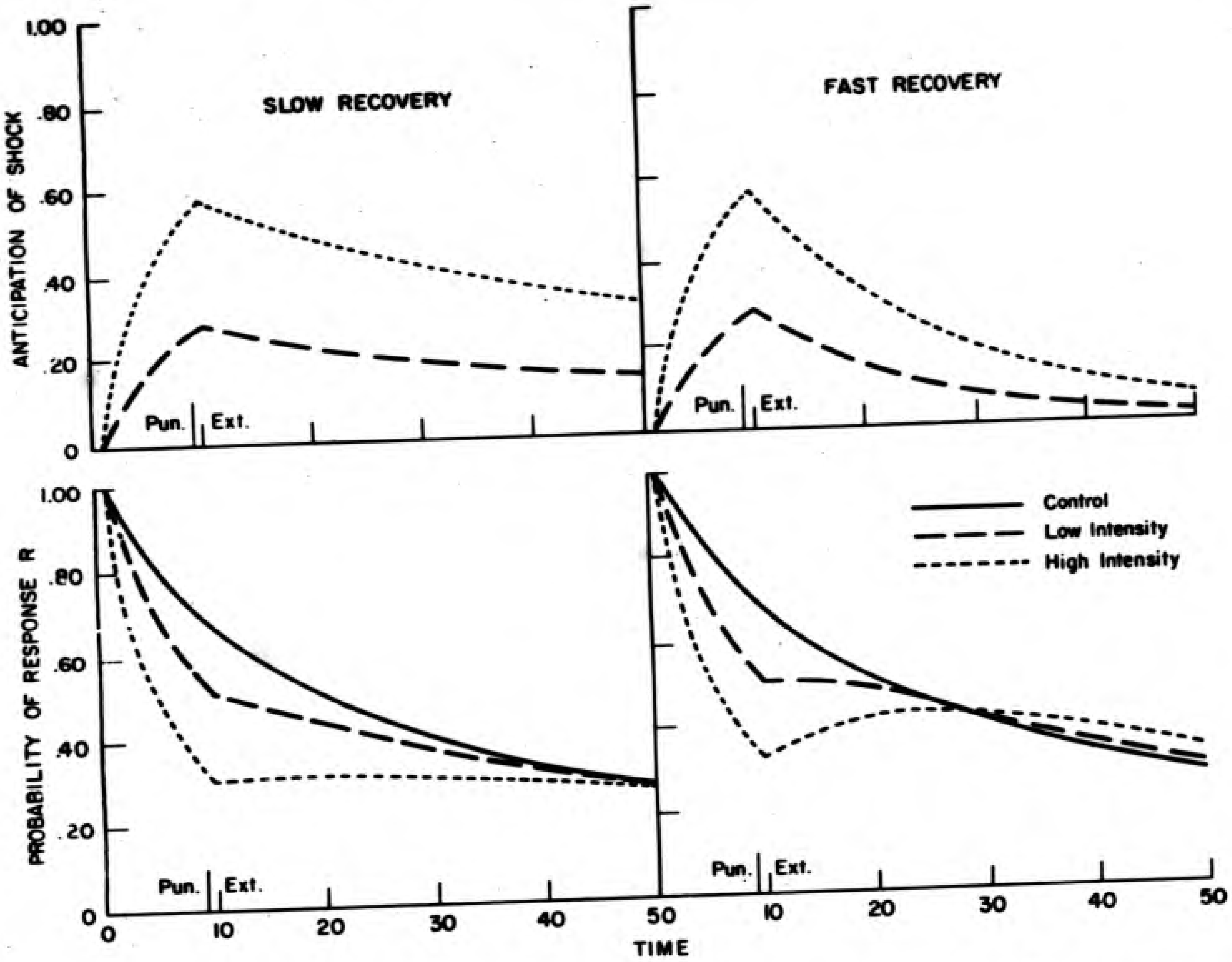

Figure 4. -- Illustrative extinction curves for free responding experiment. All conditions and parameter values are the same as for corresponding curves in Figure 3, but response probability is plotted as a function of time rather than trials.

the curve of response probability for previously punished animals ultimately crossing the control curve and running above it for a time before they ultimately converge to a common asymptote.

The reason for these differences in the free responding case is that extinction of the conditioned associative relationship between cues involved in the response occurrence and the activity of the negative drive system evoked by shock can be extinguished only on occasions when response occurs so that the cues are present in the absence of shock. In the free operant situation the punished animal may cease responding for a considerable period, during which the tendency to anticipate punishment following responses is protected from extinction, thus delaying recovery; but at the same time the tendency to anticipate reward following occurrences of the reference response is protected from extinction, thus setting the stage for compensatory recovery when the effects of punishment do ultimately extinguish. Both the delay in recovery and the compensation will be functions of the frequency and intensity of the punishing stimulus during the preceding period of punishment; with punishment of low intensity recovery may be early with substantial compensation; with punishment of high intensity, recovery may be so delayed that no appreciable compensation is ever observed.

VI. Comparison of the Present Approach with Others

In one respect the present theory represents a simplification of the currently most widely accepted interpretation of punishment, since the two principal factors of CER-CAR theory come down to one in the present formulation. In my own earlier theory (Estes, 1944) and in the approach espoused by such recent investigators as Church (1963) and Solomon (1964), the principal effects of punishment involve two stages, the establishment of a conditioned emotional state, which may be termed fear or anxiety, and then the learning of avoidance responses, the reinforcement for this learning being a reduction of the emotional state. The interpretation of Dinsmoor (1954) was similar except that Dinsmoor preferred to speak of the acquisition of aversive properties by stimuli preceding the punished response and the learning of competing behaviors which enabled the animal to escape from the aversive stimulation.

In the present theory the establishment of a CER to cues associated with the initiation of a punished response is the primary mechanism and it is assumed to be a sufficient basis for the characteristic phenomena of punishment. Although under suitable circumstances active avoidance responses may indeed be learned in situations involving punishment, I believe that these are not necessary to account for the suppressive effects of punishment. Rather than accounting for the suppressive effects in terms of avoidance learning, I would say that the suppression normally occurs first and sets the stage for avoidance learning. The main contribution of the latter is to delay or prevent recovery from the effects of punishment if the avoidance response keeps the organism from re-exposing itself to the stimuli which originally evoked the punished response.

The present interpretation of drive differs in one major respect from my own earlier formulations (Estes, 1958). In the initial development of a stimulus sampling theory of drive. I remained carefully noncommittal as to whether drive-inducing operations, such as deprivations, affect the probabilities of occurrence only of interoceptive or of both interoceptive and exteroceptive stimuli. Now I propose specifically to assume the latter. The immediate effect of an increase in activity of any drive system in the generation of an input of facilitative, or amplifier, elements which summate with (in the terminology preferred by some investigators, e.g., Campbell & Sheffield, 1953, "lower the thresholds of") the set of stimuli, internal or external in origin, associated with the system. One consequence of this facilitatory input will be increased sampling probabilities of visceral cues which provide the basis for drive discriminations. Another will be the increased probability that behaviors associated with the system, e.g., consummatory responses, will be evoked by their discriminative stimuli.

Unlike Hull's (1943) theory, the present formulation assumes no general energizing factor. Rather, activity from a particular drive system will "energize," that is facilitate the occurrence of, some classes of responses and suppress others. The innate organization of the organism's drive systems is assumed to be such that activity in any one system originally leads to facilitation of a family of responses, consummatory responses in some cases, flight and attack responses in others. Then through conditioning these facilitative effects are extended to other stimuli and additional stimulus-response units are, so to speak, assimilated into the system. On the other hand, one of the divergences between my original formulation and that of Hull has been reduced. Whereas in the model sketched in my 1958 paper, effects of drive variables and discriminative stimuli can only combine additively in the determination of response probability, the present assumption is that the facilitative effect of drive input upon stimulus sampling probabilities is multiplicative as in the combination of drive and habit factors in Hull's theory. There is no basic distinction in the present theory corresponding to that between drive and incentive (D and K) in Hull's system, except perhaps, the recognition that variations in activity of drive systems are influenced both by long term conditions such as deprivation and more local ones such as unconditioned stimuli for consummatory behaviors.

The idea of a reciprocal interaction between mechanisms of reward and punishment has been put forward, with considerable supporting evidence, by several recent investigators working within a more physiological framework, notably Miller (1963) and Stein (1964). In each of these proposals, it has been tentatively assumed that rewards arouse a "go," or activating mechanism, possibly hypothalamic in locus, which intensifies ongoing behaviors; that punishments arouse a "stop" mechanism, which exerts precisely the opposite effect; and that these mechanisms are to some extent mutually inhibiting. These notions have impressed me as exremely promising, and the analyses advanced by Miller and Stein have influenced the direction of my own reformulation. However, as indicated in preceding sections, a model differing in some specific assumptions from those hitherto proposed appears to have some advantages with regard to simplicity and the range of phenomena that can be handled. Concerning the suppressive effects of punishment, in particular, it seems to me that a "stop" mechanism operating directly on responses would have a more disorganizing effect on behavior than is ordinarily observed, and would not readily yield the qualitatively different effects of punishing stimuli that are well known to occur under different motivating conditions.

Finally, the notion of feedback is important in the present theory, as in a number of other contemporary approaches. However, the primary feedback relation in the present theory is different in important respects from that assumed by, e.g., Mowrer (1960) and Stein (1964). In both of the latter approaches, it is assumed that, as a result of a learning process, responses which have been followed by rewards or punishments come to evoke facilitatory or inhibitory feedback. However, the critical relation is that between the feedback and the response which evoked it. Thus, Mowrer's approach has been criticized by Miller (1963) on the grounds that this type of feedback does not account for the effects of reward or punishment upon response selection, since the response must occur before it can generate the positive or negative feedback. In the present theory, the feedback operates primarily in a forward rather than a backward direction; that is, a response which has previously been rewarded comes to instigate the activity of a positive drive system which facilitates the occurrence of behaviors that normally follow in the consummatory chain.

Upon being returned to a situation in which reward has been obtained, the organism is not required by the present model to search its entire response repertoire until it finds a response carrying positive feedback, as is apparently the case in Mowrer's scheme. Rather, when the organism samples some cue in the situation, the last associated response is activated, simply as a result of conditioning by contiguity. If this response was a member of a sequence leading to reward, facilitative feedback will be generated, increasing the probability that the given sequence will run to completion. If not, the stimulus sampling process continues. The stimulus amplifier theory assumes a major role for a scanning, or VTE, process in response selection, but it is the set of available stimuli which is scanned, not the set of possible responses. The function of rewards occurring on previous trials is, in effect, to alter the relative weights of the various available stimuli, and thus to bias the scanning process in favor of stimuli whose associated responses have led to reward.

Summary

The theories of punishment considered in this chapter fall into three main categories which may be denoted, for brevity, (1) unlearning, (2) new learning, and (3) suppression theories. Accumulating evidence appears to support the decision, arrived at through various routes by most theorists from Thorndike onward, against a theory of the first type, which would attribute to response-contingent punishing stimuli a unique property of weakening stimulus response associations. The most influential theory of the second type in recent years has been one assuming a two-stage process, the immediate effect of punishment being to establish a conditioned emotional state which in turn leads to the reinforcement of avoidance responses through fear or anxiety reduction. Although the learning of avoidance responses, as envisaged in this interpretation, doubtless occurs in some situations involving punishment, I believe no satisfactory case has been made for such a process as a necessary condition for the principal phenomena of punishment. According to the third view, cues originally evoking a punished response become conditioned stimuli for a conditioned emotional reaction which suppresses the ongoing behavior directly, the effect not necessarily being mediated by any type of direct competition between approach and avoidance responses. The conclusion of the present review is that the suppression theory is descriptively adequate, but that earlier versions are incomplete in that they provide no adequate theoretical basis for the suppressive effects.

In the revised suppression theory outlined in this paper, the primary mechanism of punishment is not a competition of responses but rather a competition of motives. The principal assumptions are (1) that maintenance of any type of non-reflex behavior involves the summation of discriminative or conditioned stimuli with the input of amplifier or, facilitative, elements from drive sources, and (2) that the activation of negative drive systems by pain or the anticipation of pain reciprocally inhibits amplifier input from positive drive sources. Thus, a stimulus which has preceded a traumatic event, e.g., shock, as in the typical CER or punishment paradigm, acquires the capacity of inhibiting the input of amplifier elements from sources associated with hunger, thirst, and the like. If, then, while the animal is performing an instrumental response for, say, food reward, this conditioned stimulus is presented, the facilitative drive input will be reduced and so also the probability or rate of the instrumental response. If, on the other hand, the same stimulus is introduced while the animal is performing a response for escape from shock, there will be no similar reciprocal inhibition between drive sources and thus no suppressive effect.

The revised theory accounts for the classical parametric relationships of punishment studies, including effects of delay and intensity of punishment, and amount of previous training of the punished response, the differences between response contingent and noncontingent punishment, and the attenuation of punishment by adaptation to stimuli in the absence of opportunity for responding. Also, detailed predictions are derivable regarding the course of recovery from punishment following different types of training, including specifications of conditions under which compensatory recovery may be expected. Finally, the revised formulation appears to represent a distinct advance over my earlier one in that it provides a means of interpreting temporal and order effects in situations involving both reward and punishment, and a rationale for the differential effects of punishment upon behaviors maintained by appetitive and aversive sources of motivation.

References

Boe, E. B. Bibliography on primary punishment. In R. M. Church and B. A. Campbell (Eds.), *Punishment and aversive behavior*. New York: Appleton-Century-Crofts, in press.

Brown, J. S., Martin, R. C., & Morrow, M. W. Self punitive behavior in the rat: Facilitative effects of punishment on resistance to extinction. *J. comp. physiol. Psychol.*, 1964, *57*, 127-133.

Campbell, B. A., & Sheffield, F. D. Relation of random activity to food deprivation. *J. comp. physiol. Psychol.*, 1953, *46*, 320-322.

Church, R. M. The varied effects of punishment on behavior. *Psychol. Rev.*, 1963, *70*, 369-402.

Dinsmoor, J. A. Punishment: I. The avoidance hypothesis. *Psychol. Rev.*, 1954, *61*, 34-46.

Estes, W. K. An experimental study of punishment. *Psychol. Monogr.*, 1944, *57*, (3, whole no. 263).

Estes, W. K. Toward a statistical theory of learning. *Psychol. Rev.*, 1950, *57*, 94-107.

Estes, W. K. Stimulus-response theory of drive. In M. R. Jones (Ed.), *Nebraska symposium on motivation*. Lincoln, Nebraska: Nebraska Univer. Press, 1958, 35-68.

Estes, W. K. The statistical approach to learning theory. In S. Koch (Ed.), *Psychology: A study of a science*. Vol. 2. New York: McGraw-Hill, 1959, 380-491.

Estes, W. K., & Skinner, B. F. Some quantitative properties of anxiety. *J. exp. Psychol.*, 1951, *29*, 390-400.

Fowler, H., & Wischner, G. J. The varied functions of punishment in discrimination learning. In R. M. Church and B. A. Campbell (Eds.), *Punishment and aversive behavior*. New York: Appleton-Century-Crofts, in press.

Guthrie, E. R. *The psychology of learning*. New York: Harper, 1952.

Herrnstein, R. J., & Sidman, M. Avoidance conditioning as a factor in the effects of unavoidable shocks on food-reinforced behavior. *J. comp. physiol. Psychol*., 1958, 51, 380-385.

Hull, C. L. *Principles of behavior*. New York: Appleton-Century-Crofts, 1943.

Hull, C. L. *A behavior system*. New Haven: Yale Univer. Press, 1952.

LaBerge, D. L. A model with neutral elements. In W. K. Estes and R. R. Bush (Eds.), *Studies in mathematical learning theory*. Stanford, California: Stanford Univer. Press, 1959.

Martin, R. C., & Melvin, K. B. Vicious circle behavior as a function of delay of punishment. *Psychonomic Sci*., 1964, *1*, 415-416.

Miller, N. E. Some reflections on the law of effect produce a new alternative to drive reduction. In M. R. Jones (Ed.), *Nebraska symposium on motivation*. Lincoln, Nebraska: Nebraska Univer. Press, 1963, 65-112.

Mowrer, O. H. *Learning theory and behavior*. New York: Wiley, 1960.

Muenzinger, K. F. Motivation in learning: II. The function of electric shock for right and wrong responses in human subjects. *J. exp. Psychol*., 1934, *17*, 439-448. (b)

Pfaffmann, C., & Bare, J. K. Gustatory thresholds of normal and adrenalectomized rats. *J comp. physiol. Psychol*., 1950, 43, 320-324.

Rescorla, R. A. Probability of shock in the presence and absence of CS as determinants of fear conditioning. J. comp. physiol. Psychol., 1968, in press.

Skinner, B. F. The behavior of organisms. New York: Appleton-Century-Crofts, 1938.

Solomon, R. L. Punishment. Amer. Psychologist, 1964, 19, 239-254.

Spence, K. H. Behavior theory and conditioning. New Haven: Yale Univer. Press, 1956.

Stein, L. Reciprocal action of reward and punishment mechanisms. In R. G. Heath (Ed.), The role of pleasure in behavior. New York: Harper & Row, 1964.

Thorndike, E. L. Human learning. New York: Appleton-Century-Crofts, 1931.

Thorndike, E. L. The psychology of wants, interests, and attitudes. New York: Appleton-Century-Crofts, 1935.

Tolman, E. C. Purposive behavior in animals and men. New York: Appleton-Century-Crofts, 1932.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY *(Corporate author)*
Stanford University
Institute for Mathematical Studies in the Social Sciences, Stanford, California 94305

2a REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b GROUP

3 REPORT TITLE
Outline of a Theory of Punishment

4 DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Technical Report, October 1967

5 AUTHOR(S) *(Last name, first name, initial)*
Estes, W. K.

6 REPORT DATE
10/1/67

7a TOTAL NO OF PAGES
41

7b NO OF REFS
29

8a CONTRACT OR GRANT NO
Nonr-225(73)

b. PROJECT NO.
NR 154 218

c.

d.

9a ORIGINATOR'S REPORT NUMBER(S)
Technical Report No. 123

9b OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10 AVAILABILITY/LIMITATION NOTICES
Distribution of this document is unlimited.

11 SUPPLEMENTARY NOTES

12 SPONSORING MILITARY ACTIVITY
Office of Naval Research
Personnel and Training Branch, Code 458
Washington, D. C. 20360

13 ABSTRACT

In the revised suppression theory outlined in this paper, the primary mechanism of punishment is not a competition of responses but rather a competition of motives. The principal assumptions are, (1) that maintenance of non-reflex behavior involves the summation of discriminative stimuli with the input of amplifier or, facilitative, elements from drive sources, and (2) that the activation of negative drive systems by pain or the anticipation of pain reciprocably inhibits amplifier elements from positive drive sources.

The revised theory accounts for the classical parametric relationships of punishment studies, including effects of delay, intensity, and amount of previous training of the punished response, the differences between response contingent and noncontingent punishment, and the attenuation of punishment by adaptation to stimuli and the absence of opportunity for responding. Also, detailed predictions are derivable regarding the course of recovery from punishment following different types of training, including specifications of conditions under which compensatory recovery may be expected.

DD FORM 1 JAN 64 1473

UNCLASSIFIED
Security Classification

UNCLASSIFIED

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Punishment Suppression Theory Feedback Model						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers *(either by the originator or by the sponsor),* also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through

____ ."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through

____ ."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through

____ ."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C),* or *(U).*

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

(Continued from inside front cover)

36 G. H. Bower. Response strengths and choice probability: A consideration of two combination rules. December 19, 1960. (In E. Nagel, P. Suppes, and A. Tarski (Eds.), Logic, Methodology and Philosophy of Science: Proceedings of the 1960 International Congress. Stanford Univ. Press, 1962. Pp. 400-412)

37 G. H. Bower. Application of the all-or-none conditioning model to the learning of compound responses. June 7, 1961.

38 P. Suppes and M. Schlag-Rey. Test of some learning models for double contingent reinforcement. August 15, 1961. (Psychol. Rep., 1962,

39 P. Suppes and R. Ginsberg. A fundamental property of all-or-none models, binomial distribution of responses prior to conditioning, with application to concept formation in children. September 20, 1961. (Psychol. Rev., 1963, 70, 139-161)

40 J. Theios. A three-state Markov model for learning. September 22, 1961. (Simple conditioning as two-stage all-or-none learning, Psychol. Rev., 1963, 70, 403-417)

41 G. H. Bower. General three-state Markov learning models. September 26, 1961.

42 R. C. Atkinson. A variable threshold model for signal detection. November 17, 1961.

43 R. C. Atkinson. Mathematical models in research on perception and learning. December 25, 1961. (In M. H. Marx (Ed.), Theories in Contemporary Psychology. New York: Macmillan Co., 1963. Pp. 551-564)

44 P. Suppes. Towards a behavioral foundation of mathematical proofs. January 2, 1962. (In K. Ajdukiewicz (Ed.), The Foundations of Statements and Decisions: Proceedings of the International Colloquium on Methodology of Sciences, September 18-23, 1961. Warszawa: PWN-Polish Scientific Publishers, 1965. Pp. 327-341)

45 P. Suppes and J. L. Zinnes. Basic measurement theory. March 15, 1962. (Chapter I in R. R. Bush, E. H. Galanter, and R. D. Luce (Eds.), Handbook of Mathematical Psychology, Vol. I. New York: John Wiley, 1963)

46 R. C. Atkinson, E. C. Carterette, and R. A. Kinchla. Sequential phenomena in psychophysical judgments: a theoretical analysis. April 20, 1962. (Institute of Radio Engineers Transactions on Information Theory, 1962, IT-8, S 155-162)

47 R. C. Atkinson. A variable sensitivity theory of signal detection. May 18, 1962. (Psychol. Rev., 1963, 70, 91-106)

48 R. C. Atkinson and W. K. Estes. Stimulus sampling theory. July 1, 1962. (Chapter 10 in R. R. Bush, G. H. Galanter, and R. D. Luce (Eds.), Handbook of Mathematical Psychology, Vol. II. New York: Wiley, 1963)

49 P. Suppes, E. Crothers, R. Weir, and E. Trager. Some quantitative studies of Russian consonant phenome discrimination. September 14, 1962.

50 R. C. Atkinson and R. C. Calfee. Mathematical learning theory. January 2, 1963. (In B. B. Wolman (Ed.), Scientific Psychology. New York: Basic Books, Inc., 1965. Pp. 254-275)

51 P. Suppes, E. Crothers, and R. Weir. Application of mathematical learning theory and linguistic analysis to vowel phoneme matching in Russian words. December 28, 1962.

52 R. C. Atkinson, R. Calfee, G. Sommer, W. Jeffrey and R. Shoemaker. A test of three models for stimulus compounding with children. January 29, 1963. (J. exp. Psychol., 1964, 67, 52-58)

53 E. Crothers. General Markov models for learning with inter-trial forgetting. April 8, 1963.

54 J. L. Myers and R. C. Atkinson. Choice behavior and reward structure. May 24, 1963. (Journal math. Psychol., 1964, 1, 170-203)

55 R. E. Robinson. A set-theoretical approach to empirical meaningfulness of measurement statements. June 10, 1963.

56 E. Crothers, R. Weir and P. Palmer. The role of transcription in the learning of the orthographic representations of Russian sounds. June 17, 1963.

57 P. Suppes. Problems of optimization in learning a list of simple items. July 22, 1963. (In Maynard W. Shelly, II and Glenn L. Bryan (Eds.), Human Judgments and Optimality. New York: Wiley. 1964. Pp. 116-126)

58 R. C. Atkinson and E. J. Crothers. Theoretical note: all-or-none learning and intertrial forgetting. July 24, 1963.

59 R. C. Calfee. Long-term behavior of rats under probabilistic reinforcement schedules. October 1, 1963.

60 R. C. Atkinson and E. J. Crothers. Tests of acquisition and retention, axioms for paired-associate learning. October 25, 1963. (A comparison of paired-associate learning models having different acquisition and retention axioms, J. math. Psychol., 1964, 1, 285-315)

61 W. J. McGill and J. Gibbon. The general-gamma distribution and reaction times. November 20, 1963. (J. math. Psychol., 1965, 2, 1-18)

62 M. F. Norman. Incremental learning on random trials. December 9, 1963. (J. math. Psychol., 1964, 1, 336-351)

63 P. Suppes. The development of mathematical concepts in children. February 25, 1964. (On the behavioral foundations of mathematical concepts. Monographs of the Society for Research in Child Development, 1965, 30, 60-96)

64 P. Suppes. Mathematical concept formation in children. April 10, 1964. (Amer. Psychologist, 1966, 21, 139-150)

65 R. C. Calfee, R. C. Atkinson, and T. Shelton, Jr. Mathematical models for verbal learning. August 21, 1964. (In N. Wiener and J. P. Schoda (Eds.), Cybernetics of the Nervous System: Progress in Brain Research. Amsterdam, The Netherlands: Elsevier Publishing Co., 1965. Pp. 333-349)

66 L. Keller, M. Cole, C. J. Burke, and W. K. Estes. Paired associate learning with differential rewards. August 20, 1964. (Reward and information values of trial outcomes in paired associate learning. (Psychol. Monogr., 1965, 79, 1-21)

67 M. F. Norman. A probabilistic model for free-responding. December 14, 1964.

68 W. K. Estes and H. A. Taylor. Visual detection in relation to display size and redundancy of critical elements. January 25, 1965, Revised 7-1-65. (Perception and Psychophysics, 1966, 1, 9-16)

69 P. Suppes and J. Donio. Foundations of stimulus-sampling theory for continuous-time processes. February 9, 1965.

70 R. C. Atkinson and R. A. Kinchla. A learning model for forced-choice detection experiments. February 10, 1965. (Br. J. math stat. Psychol., 1965, 18, 184-206)

71 E. J. Crothers. Presentation orders for items from different categories. March 10, 1965.

72 P. Suppes, G. Groen, and M. Schlag-Rey. Some models for response latency in paired-associates learning. May 5, 1965. (J. math. Psychol., 1966, 3, 99-128)

73 M. V. Levine. The generalization function in the probability learning experiment. June 3, 1965.

74 D. Hansen and T. S. Rodgers. An exploration of psycholinguistic units in initial reading. July 6, 1965.

75 B. C. Arnold. A correlated urn-scheme for a continuum of responses. July 20, 1965.

76 C. Izawa and W. K. Estes. Reinforcement-test sequences in paired-associate learning. August 1, 1965.

77 S. L. Blehart. Pattern discrimination learning with Rhesus monkeys. September 1, 1965.

78 J. L. Phillips and R. C. Atkinson. The effects of display size on short-term memory. August 31, 1965.

79 R. C. Atkinson and R. M. Shiffrin. Mathematical models for memory and learning. September 20, 1965.

80 P. Suppes. The psychological foundations of mathematics. October 25, 1965.

(Continued on back cover)

(Continued from inside back cover)

81 P. Suppes. Computer-assisted instruction in the schools: potentialities, problems, prospects. October 29, 1965.
82 R. A. Kinchla, J. Townsend, J. Yellott, Jr., and R. C. Atkinson. Influence of correlated visual cues on auditory signal detection. November 2, 1965. (*Perception and Psychophysics*, 1966, *1*, 67-73)
83 P. Suppes, M. Jerman, and G. Groen. Arithmetic drills and review on a computer-based teletype. November 5, 1965.
84 P. Suppes and L. Hyman. Concept learning with non-verbal geometrical stimuli. November 15, 1965.
85 P. Holland. A variation on the minimum chi-square test. November 18, 1965.
86 P. Suppes. Accelerated program in elementary-school mathematics -- the second year. November 22, 1965.
87 P. Lorenzen and F. Binford. Logic as a dialogical game. November 29, 1965.
88 L. Keller, W. J. Thomson, J. R. Tweedy, and R. C. Atkinson. The effects of reinforcement interval on the acquisition of paired-associate responses. December 10, 1965.
89 J. I. Yellott, Jr. Some effects on noncontingent success in human probability learning. December 15, 1965.
90 P. Suppes and G. Groen. Some counting models for first-grade performance data on simple addition facts. January 14, 1966.
91 P. Suppes. Information processing and choice behavior. January 31, 1966.
92 G. Groen and R. C. Atkinson. Models for optimizing the learning process. February 11, 1966.
93 R. C. Atkinson and D. Hansen. Computer-assisted instruction in initial reading: Stanford project. March 17, 1966.
94 P. Suppes. Probabilistic inference and the concept of total evidence. March 23, 1966.
95 P. Suppes. The axiomatic method in high-school mathematics. April 12, 1966.
96 R. C. Atkinson, J. W. Brelsford, and R. M. Shiffrin. Multi-process models for memory with applications to a continuous presentation task. April 13, 1966.
97 P. Suppes and E. Crothers. Some remarks on stimulus-response theories of language learning. June 12, 1966.
98 R. Bjork. All-or-none subprocesses in the learning of complex sequences. June 22, 1966.
99 E. Gammon. The statistical determination of linguistic units. July 1, 1966.
100 P. Suppes, L. Hyman, and M. Jerman. Linear structural models for response and latency performance in arithmetic. July 29, 1966.
101 J. L. Young. Effects of intervals between reinforcements and test trials in paired-associate learning. August 1, 1966.
102 H. A. Wilson. An investigation of linguistic unit size in memory processes. August 3, 1966.
103 J. T. Townsend. Choice behavior in a cued-recognition task. August 8, 1966.
104 W. H. Batchelder. A mathematical analysis of multi-level verbal learning. August 9, 1966.
105 H. A. Taylor. The observing response in a cued psychophysical task. August 10, 1966.
106 R. A. Bjork. Learning and short-term retention of paired associates in relation to specific sequences of interpresentation intervals. August 11, 1966.
107 R. C. Atkinson and R. M. Shiffrin. Some Two-process models for memory. September 30, 1966.
108 P. Suppes and C. Ihrke. Accelerated program in elementary-school mathematics--the third year. January 30, 1967.
109 P. Suppes and I. Rosenthal-Hill. Concept formation by kindergarten children in a card-sorting task. February 27, 1967.
110 R. C. Atkinson and R. M. Shiffrin. Human memory: a proposed system and its control processes. March 21, 1967
111 Theodore S. Rodgers. Linguistic considerations in the design of the Stanford computer-based curriculum in initial reading. June 1, 1967
112 Jack M. Knutson. Spelling drills using a computer-assisted instructional system. June 30, 1967.
113 R. C. Atkinson. Instruction in initial reading under computer control: the Stanford Project. July 14, 1967.
114 J. W. Brelsford, Jr. and R. C. Atkinson. Recall of paired-associates as a function of overt and covert rehearsal procedures. July 21, 1967.
115 J. H. Stelzer. Some results concerning subjective probability structures with semiorders. August 1, 1967.
116 D. E. Rumelhart. The effects of interpresentation intervals on performance in a continuous paired-associate task. August 11, 1967.
117 E. J. Fishman, L. Keller, and R.E. Atkinson. Massed vs. distributed practice in computerized spelling drills. August 18, 1967.
118 G. J. Groen. An investigation of some counting algorithms for simple addition problems. August 21, 1967.
119 H. A. Wilson and R. C. Atkinson. Computer-based instruction in initial reading: a progress report on the Stanford Project. August 25, 1967.
120 F. S. Roberts and P. Suppes. Some problems in the geometry of visual perception. August 31, 1967.
121 D. Jamison. Bayesian decisions under total and partial ignorance. D. Jamison and J. Kozielecki. Subjective probabilities under total uncertainty. September 4, 1967.
122 R. C. Atkinson. Computerized instruction and the learning process. September 15, 1967.
123 W. K. Estes. Outline of a theory of punishment. October 1, 1967.