

Twenty Years of Classical Conditioning with the Rabbit

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I. Introduction

The present chapter is intended to review the behavioral methods and findings of classical conditioning with the rabbit, particularly with the rabbit nictitating membrane response (NMR) preparation. A companion piece by Thompson *et al.*, reviewing the burgeoning body of neuro-biological research using the NMR preparation, may be found in the chapter by Thompson *et al.* in this volume. Although research findings with the rabbit preparations may be regarded as a set of biopsychological phenomena which stand by themselves, the significance of these phenomena is derived not only from the quality of the data but also from their relevance to long-standing questions regarding the nature of learned behavior. In a historical context, classical conditioning with the rabbit can be viewed from at least three perspectives: as laboratory models of associative learning (Gormezano, 1972; Gormezano and Kehoe, 1981); as laboratory models of behavioral adaptation (Gormezano, 1965; Gormezano and Coleman, 1973); and as sources of axioms for theories regarding the mediation of extended sequences of goal-directed activity (Gormezano and Kehoe, 1975, 1982). Accordingly, the present chapter will attempt to place classical conditioning with rabbit preparations in its broader experimental and theoretical contexts.

II. Historical and Methodological Background

A. CLASSICAL CONDITION AND ASSOCIATIONISM

In psychological research and theory, classical conditioning has frequently occupied the cleft between complex behavior and its neural substrate. Pavlov (1927) himself saw his conditioned reflex method as a tool for revealing the functional properties of higher neural processes and, more broadly, for the study of neural mechanisms governing the behavioral adaptation of an individual animal to the exigencies of its environment. However, Pavlov made only modest attempts to coordinate his extensive behavioral observations with an empirical investigation of neural processes. In the context of behavior theory, Bekhterev (1913), Pavlov's more psychologically oriented contemporary, was the first to propose classical conditioning as a prototypical example of association by contiguity. One of the earliest and still most useful statements in the American literature regarding the relationship of classical conditioning to associative learning was articulated by Lashley (1916, pp. 459-460). In particular, he saw classical conditioning as possessing several methodological advantages over the then prevailing trial-and-error procedures:

Conditions may be so arranged that only two stimuli, and presumably, one reaction are involved . . . , but its greatest usefulness should be for studies of the temporal relation between the primary and associated stimulus necessary for the formation of the association.

The fact that a single reaction is involved is an advantage. The associated reaction either does, or does not, occur and there is no question of the elimination of errors or simplification of reaction.

Thus, Lashley noted that the classical conditioning method permits the investigator precision in the control of stimuli and in the measurement of responses to delineate clearly the effects of important associative variables.

The recognition of the methodological advantages of classical conditioning led initially to an extravagant use of conditioning concepts as identical to associative doctrine and as mechanisms of learning (Frank, 1923; cf. Gormezano and Kehoe, 1981; Holt, 1931; Smith and Guthrie, 1921; Watson, 1925; Wilson, 1924). The speculative use of classical conditioning ended with the appearance of detailed descriptions of Pavlov's (1927, 1928) work and experimental reports in the United States which revealed the complexities of classical conditioning (e.g., Cason, 1922; Hilgard, 1931). Despite the more sober view regarding the role of classical conditioning in psychology, there has continued to be a strong identification of "conditioning" and "contiguity," which fails to do justice to either the complexities of the empirical phenomena or the sophistication of philosophical associationism (Hilgard, 1937; Robinson, 1932).

Few associative theories in philosophy or psychology have specified the contiguity between events as the single sufficient condition for the establishment of a new association. Little thought on the matter is required to conclude that not every pair of sensations, ideas, or events which occur together are necessarily later recalled together. In philosophical associationism, the Law of Frequency acknowledged that a single repetition of a pair of events is not sufficient to establish an association. Furthermore, lists of Secondary Laws of Association specified as determinants of association such factors as the intensity of the events and the number of other associations involving members of the pair (Brown, 1820/1977; pp. 199-214). In addition, the philosophical associationists devoted a large portion of their writings to a consideration of principles for describing the organization of pairwise associations into unified perceptions and coherent streams of memories. Similar constraints on the effectiveness of contiguity and organizing principles for multiple associations may be found in virtually every associationistic learning theory (cf. Gormezano and Kehoe, 1981).

Empirically, investigations of classical conditioning and, for that matter, most other learning paradigms have revealed counterparts to the philosophical Law of Frequency and the other Secondary Laws. Moreover, it has be-

come clear that previous theoretical constraints on a contiguity principle were insufficient to account for associative learning in two types of complex situations. First, research with compound stimuli has produced an accumulation of evidence that a conditioned response (CR) acquisition to one conditioned stimulus (CS) as a result of otherwise effective CS-unconditioned stimulus (US) pairings may be impaired in lawful ways by the presence of other CSs during training; these findings have been collectively known as "stimulus selection" or "selective association" phenomena (Gormezano and Kehoe, 1981; Rudy and Wagner, 1975). Second, research in which a CS and a US are intermixed but not always paired has revealed that the level of conditioning may vary as a function of the overall "correlation" or "contingency" between the CS and the US (Prokasy, 1965; Rescorla, 1967, 1972). Consequently, the trend of theorizing has been toward formulations which retain an axiomatic contiguity principle but assume that additional processes of competition between stimuli and/or inhibition are intimately involved in the formation of associations (Mackintosh, 1975; Rescorla, 1972; Rescorla and Wagner, 1972). Finally, a more fundamental challenge to a blind application of the Law of Contiguity has existed since the first systematic studies of classical conditioning in the United States, which revealed that CR acquisition failed to occur when the CS and US were truly contiguous, i.e., simultaneous, but did occur when there was some degree of asynchrony between the two stimuli (Bernstein, 1934). Together, these theoretical and empirical considerations militate against the comfortable but simpleminded identification of the empirical laws of classical conditioning with the doctrines of philosophical associationism (Hilgard, 1937).

B. DEFINITION OF ASSOCIATIVE LEARNING

Although the identification of classical conditioning with the Law of Contiguity is inaccurate, the use of associative doctrine has nonetheless provided a useful guide to the basic methodology, research, and theory of classical conditioning in Western laboratories. What, then, is considered an instance of associative learning? Whereas a broad but still objective definition of "learning" states that a change in behavior must be a result of "experience" and must be relatively permanent (Kimble, 1961; Mpitsos *et al.*, 1978), the associative doctrine provides the additional stipulation that the experience consists of a temporal conjunction of two events. As Lashley (1916) noted, it is the full experimental control of the temporal conjunction between the intended CS and the US-unconditioned response (UR) which makes classical conditioning preparations attractive vehicles for the study of associative learning.

The above definitional concerns seem clear until one realizes that the behavioral changes denoted as learning, not to mention associative learning, must be distinguished from the continuous stream of behavior that characterizes even the most passive laboratory species. Consequently, considerable controversy and ambiguity have arisen in the identification of specific instances of learning and memory phenomena, posing a serious problem for a neurobiology of these phenomena. Put simply, it is rather difficult to identify the neural processes underlying a set of behavioral laws if there is no agreement as to which laws fall into the set. The adoption of standardized "model" preparations provides one means to finesse the lack of precise criteria for specific instances of learning and memory (Moore, 1979; Mpitsoos *et al.*, 1978; Thompson *et al.*, 1972). The use of model preparations focuses neurobiological research on preparations for which the behavioral methods and laws are relatively well delineated, thus leaving the neurobiological researcher free to discover the underlying neural processes with confidence that the behavioral phenomena are robust. Furthermore, a focus on specific behavioral preparations and on delineation of their particular underlying processes appears to encourage empirical confirmation of any perceived commonality (or difference) in process between examples of learning, thus avoiding unwarranted generalizations (or distinctions) merely on the basis of common (or different) labels.

C. CONTROL METHODOLOGY

From a behavioral viewpoint, the associative nature of a given preparation has come to be determined not only by the use of contiguous occurrence of the CS and US but also by a set of control operations intended to estimate the contribution of other possible processes to the observed response. If behavior in a classical conditioning preparation were governed strictly by an associative process, then the single observation of the designated target response to a CS after CS-US pairings would be sufficient to indicate the establishment of a CR. Not surprisingly, this ideal case has never been achieved, for not all responses observed in connection with a CS result uniquely from prior CS-US pairings. At a minimum, all response systems show some level of baseline activity, often raised by US presentations, which will produce an accidental coincidence of the CS and target responses. Moreover, the likelihood of a response to the CS may be systematically affected by (a) alpha responses, which are URs to the CS in the same effector system as the target response, and (b) "pseudo-conditioned" and "sensitized" responses, which can be established on the basis of prior US-alone presentations. Where nonassociative processes are operating, any specific response following a CS cannot in principle be ascribed to an associative process. Ac-

cordingly, to ascertain the establishment of CRs, it has been conventional to assess the contribution of the nonassociative processes to the likelihood of responses by a variety of control procedures, entailing US-alone, CS-alone, and unpaired presentations of the CS and US (Gormezano and Kehoe, 1975).

D. ORIGIN OF THE RABBIT PREPARATIONS

The rabbit preparations were initially developed by the senior author and his associates to remedy long-term deficiencies and difficulties in the study of classical conditioning. Despite the potential of classical conditioning for revealing the functional properties of higher neural processes, and despite its axiomatic status in behavior theories, there was a paucity of research in Western laboratories with preparations suitable for fulfilling both physiological and theoretical roles. In part, the relative neglect of research in classical conditioning can be attributed to the early speculative use of the term "classical conditioning" (e.g., Watson, 1925), which created the illusion that its laws had been fully specified by Pavlov (Gormezano and Kehoe, 1975, p. 145). This is not to say that there was no research in classical conditioning. Over the decades, a number of response systems were explored in humans and infrahumans for use in classical conditioning procedures (Hilgard and Marquis, 1940; Kimble, 1961), but in these concerted attempts methodological difficulties were encountered. In human eye-blink conditioning, extensive methodological work had removed many of the measurement difficulties, but the data still displayed considerable variability, and the human preparation was clearly unusable for physiological interventions. More importantly, despite the physicalistic and deterministic nature of conditioning theory stretching back to Pavlov (1927, pp. 3-5) and Bekhterev (1913), data from humans were perpetually subjected to interpretation in terms of "volitional" processes (Gormezano, 1965; Hilgard and Marquis, 1940, pp. 255-258; Peak, 1933a.; Theios, 1972; Wolfle, 1932). In both humans and animals, the other major conditioning preparations suffered from substantial intrusions by responding not attributable to associative processes. For example, in salivary and generalized stimulus-response (GSR) conditioning, the contribution of one or more of the aforementioned factors made response frequency and latency relatively insensitive indices of the effects of CS-US presentations (Gormezano, 1966; Stewart *et al.*, 1961). Consequently, to focus attention on the objective determinants of conditioning and to provide the robust data necessary to address both physiological and theoretical questions, we sought a more suitable animal preparation.

1. Conditioning of the Eyelid, Nictitating Membrane, and Eyeball Retraction Responses

In our initial experiments (Deaux and Gormezano, 1963; Gormezano et al., 1962; Schneiderman et al., 1962), it was found that rabbits, if properly restrained, remained passive even during strong stimulation, thus minimizing the problem of struggling and competing behavior that frequently attends the prolonged restraint of other nonhuman species (Gormezano, 1966). As shown in Fig. 1, each rabbit was restrained in a Plexiglas box, and either the rabbit's eyelid closure (Schneiderman et al., 1962), eyeball retraction (Deaux and Gormezano, 1963), or nictitating membrane extension (Gormezano et al., 1962) was monitored by a displacement transducer (rotary potentiometer) whose electrical signal was amplified and recorded by an ink-writing oscillograph. The CS was a 600-msec tone, and the US was a 100-msec puff of air delivered to the dorsal region of the right cornea at a CS-US interval of 500 msec. (Subsequently, the air puff US continued to be used in conjunction with electrophysiological recordings or stimulation, but

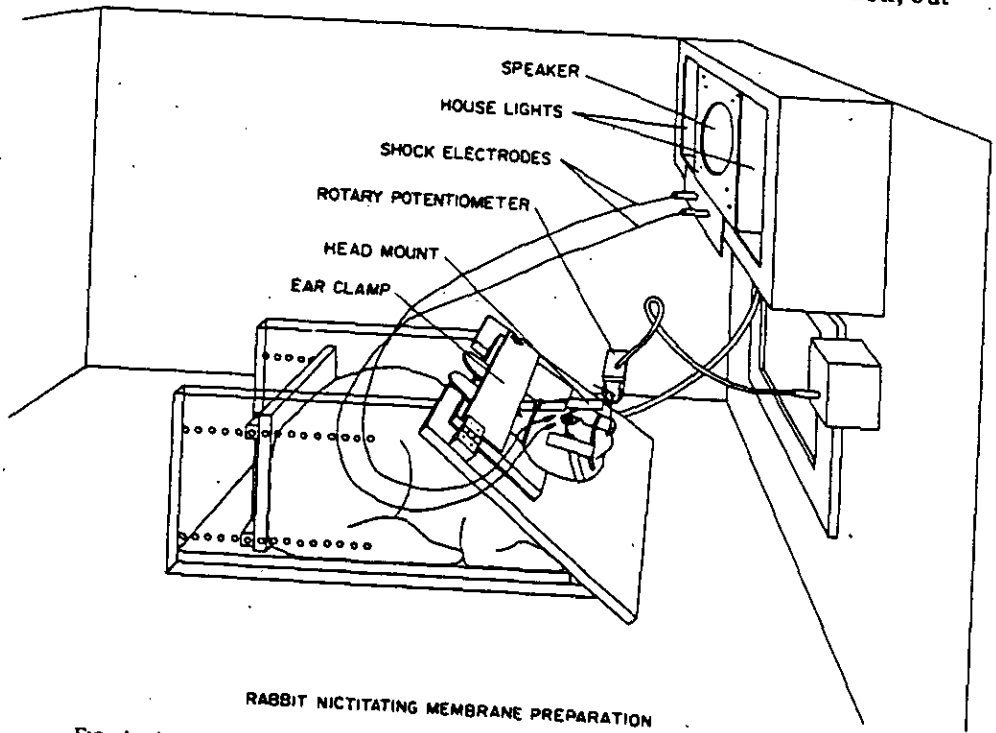


FIG. 1. A rabbit in the restraining box with headset arranged for recording from the NMR.

the majority of behavioral studies have used a US consisting of a 60-Hz electric shock administered to the paraorbital region.)

In all three response systems, initial experiments indicated that CR acquisition proceeded in a smooth fashion, with orderly changes in response frequency, latency, and amplitude. Control conditions indicated that contributions by other sources of responding were negligible. Panels A, B, and C of Fig. 2 show the results of the initial experiments with the eyelid, eyeball retraction, and nictitating membrane responses, respectively. The data are plotted as a function of trial blocks for adaptation, acquisition, and extinction. During adaptation, the rabbits were placed in the conditioning apparatus for a period equal to the length of the subsequent training sessions, but no presentations of either the CS or US occurred. A measure of the base rate of responding was obtained by scoring responses during the 500-msec periods in which the CS would later be presented. Inspection of the figure reveals that the mean likelihood of a "spontaneous" response was less than 3%. During acquisition training, the performance of CS-alone, US-alone, and unpaired control groups never exceeded 6% on any day, a level not appreciably higher than the base rate. In marked contrast, the paired CS-US experimental group showed a progressive increase in CR frequency across days to an asymptote which, for example, reached 95% CRs in the NMR preparation. With further investigations, we have been able to delineate conditioning parameters which reliably produce rapid NMR acquisition to asymptotic levels near 100% CRs within a single session of 200-300 CS-US trials (e.g., Gormezano and Coleman, 1975). [The rabbit's retractor bulbi muscle governs eyeball retraction, and the force of this mechanical action also produces a passive extension of the nictitating membrane (Gray *et al.*, 1981). However, because of its relative ease of measurement and other methodological virtues (cf. Gormezano, 1966), we have primarily employed the NMR preparation.}]

2. Jaw Movement Response (JMR) Conditioning

As a companion to the above conditioning preparations, which are based on aversive USs, the JMR preparation was developed to provide an appetitive conditioning procedure based on a US consisting of the delivery of water to the oral cavity (Smith *et al.*, 1966). As can be seen in panel A of Fig. 3, the restraint and recording apparatus are largely the same as those of the NMR preparation. However, for delivery of water under pressure to the oral cavity, each experimental chamber was equipped with a solenoid-operated liquid delivery system which terminates in a blunted hypodermic needle inserted into a polyethylene cannula permanently implanted in each rabbit's

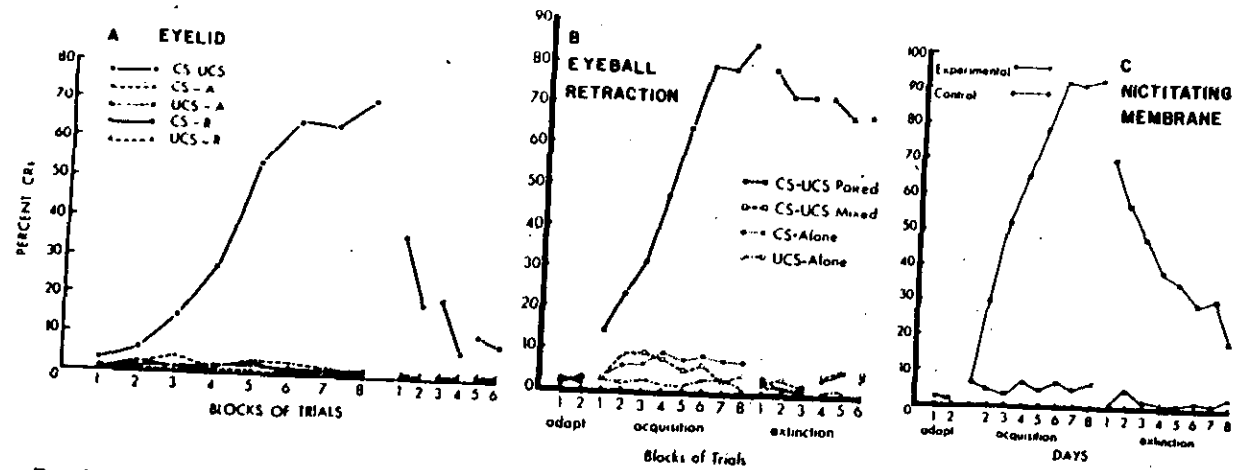


FIG. 2. (A) Mean percentage of eyelid responses plotted in 82-trial blocks during acquisition and 41-trial blocks during extinction (Schneiderman, Fuentes, & Gormezano, 1962); (B) mean percentage of eyeball retraction responses plotted in 70-trial blocks for adaptation, acquisition, and extinction (Deaux and Gormezano, 1963); (C) mean percentage of NMRs plotted in 70-trial blocks for adaptation, acquisition, and extinction. (Gormezano *et al.*, 1962.)

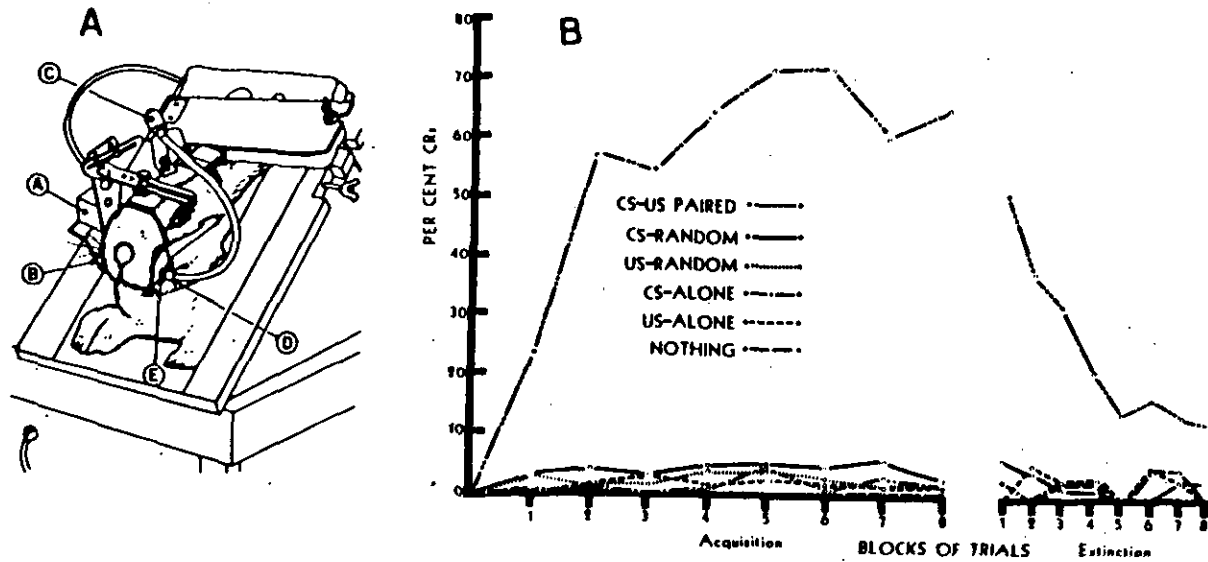


FIG. 3. The left side shows a restrained rabbit prepared for recording the JMR: (A) photo cell transducer, (B) piano-wire armature, (C) luer-lock connector; (D) blunted hypodermic needle, and (E) polyethylene cannula. The right side shows the mean percentage JMR for acquisition (40-trial blocks) and extinction (10-trial blocks).

right cheek. The rabbits were maintained on a restricted water intake to ensure reliable unconditioned JMRs.

Panel B of Fig. 3 shows the results of the initial investigation of JMR conditioning by Smith *et al.* (1966). Whereas the CS-US paired condition produced systematic increases in the JMR percentage, there was a low incidence of spontaneous responses, alpha responses, and pseudo-CRs, thus permitting an assessment of conditioning in terms of response frequency, latency, and amplitude parallel to those in the NMR preparation. Subsequent investigations (Mitchell and Gormezano, 1970; Sheafor, 1975; Sheafor and Gormezano, 1972) have revealed that there can be systematic increases in the frequency of responding attributable to pseudoconditioning. However, the frequency and amplitude of pseudo-CRs are substantially lower than those obtained for CRs with paired CS-US procedures.

3. Heart Rate Conditioning

Since the NMR as well as the JMR preparations are based on skeletal musculature, Schneiderman *et al.*, (1966) developed a preparation for conditioning the heart rate. In the original demonstration, the rabbits were held in the standard Plexiglas restrainer, the CS was a 2500-msec, 72-dB, 1000-Hz tone, and the US was a 500-msec, 1.5 mA, 60-Hz shock delivered to the pinna of the subject's right ear. Both the UR and the CR were a deceleration in the heart rate. Since the procedure produced few overt struggling responses, the rabbit heart rate response was relatively uncomplicated by gross body movement. Figure 4 shows the performance levels across days obtained from separate groups of rabbits trained with CS-US paired trials, unpaired CS and US presentations, CS-alone presentations, and US-alone presentations. Inspection of the figure reveals that animals in the paired group showed acquisition of a decelerative CR as measured on CS test trials presented after 0, 9, 18, 27, 36, and 45 training trials. In contrast, the control groups showed no systematic changes in heart rate to the CS. Subsequently, Schneiderman and his associates (Brickman and Schneiderman, 1977; Sampson *et al.*, 1974; Schneiderman, 1970, 1972) pursued an extensive program of behavioral, neurophysiological, and neurochemical investigations using the rabbit heart rate conditioning preparation.

E. RELATION OF RABBIT PREPARATIONS TO OTHER "PAVLOVIAN" PROCEDURES

During the 1950s and 1960s, research in animal learning frequently entailed free-operant procedures, in which the role of the instrumental contingency (i.e., the response-reinforcer relation) was of most interest and, con-

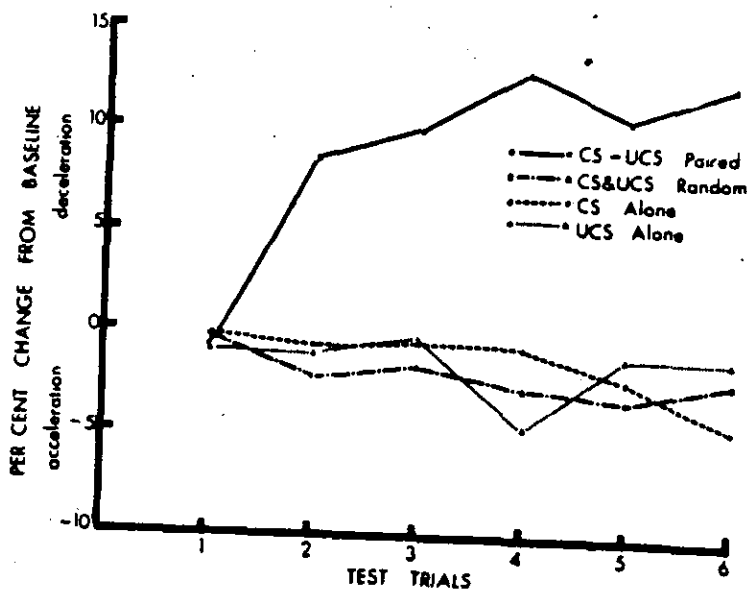


FIG. 4. The mean percentage change from baseline of the 30 beats subsequent to CS onset on each test trial for groups receiving CS-alone adaptation trials. (Schneiderman *et al.*, 1966.)

versely, in which the role of the stimulus antecedents was obscured. The 1970s witnessed a shift in research interests to the stimulus antecedents of behavior under the headings of "stimulus-reinforcer relations," "cue-to-consequence associations" and "Pavlovian conditioning." However, the resurgent interest in stimulus antecedents suffers from the historic identification of classical conditioning and association. Consequently, events that only a few years ago would have been labeled as "discriminative stimuli," "warning signals," or "cues" are now designated as CSs. By itself, the use of Pavlov's nomenclature is harmless and even useful for acknowledging the associative character of otherwise disparate learning procedures. However, the widespread use of Pavlov's terminology has been accompanied by a belief in a unitary, central associative process for which the overt behavior has become the *mere index* (e.g., Pearce and Hall, 1980). In summary, the zeitgeist has moved from a radical behaviorism, which minimizes the importance of stimulus antecedents, to an equally radical associationism, which minimizes the importance of the overt behavior. Neither zeitgeist does justice to the interesting complexities of learned behavior and its stimulus antecedents. Under the impact of the identification of associative learning with classical conditioning, the term "classical conditioning" has been extended gradually to include at least four distinct associative paradigms: (a) CS-CR, (b) CS-instrumental response (IR), (c) instrumental approach pro-

cedures, and (d) "autoshaping." All these procedures administer or purport to administer the CS and US in a response-independent fashion, but they may be distinguished by the nature of the target behavior.

1. CS-CR Paradigms

All the rabbit preparations fall into the class of CS-CR procedures, in which the CR refers to a response to the CS that appears in any effector system in which a UR is evoked by the US; the CR and UR, however, need not be identical (Gormezano and Kehoe, 1975). Thus, the CS-CR procedures are the traditional procedures which have also been described as "respondent learning" (cf. Skinner, 1937, 1938) or "learning by homogeneous reinforcement" (Hilgard and Marquis, 1940, pp. 75; 98-100). Through the US-UR, the experimenter has independent control over the occurrence of the target response system as well as the key stimulus events. With the degree of experimental control available in the CS-CR procedures, they have continued to provide the analytical power, recognized by Lashley (1916), for discovering the precise conditions for the acquisition of responding to both associative and nonassociative variables.

2. CS-IR Paradigms

The class of CS-IR paradigms includes, most notably, the conditioned suppression procedure, as well as other "transfer of control" or "classical-instrumental transfer" procedures (Gormezano and Moore, 1969; Overmier and Lawry, 1979; Rescorla and Solomon, 1967). In CS-IR procedures, the stimulus pairings of classical conditioning are carried out, but without any measurement of a CR in the sense that we have used it above. Then, in the test phase, the CS is presented during ongoing instrumental responding, and the CS's facilitory or disruptive effect on instrumental behavior is measured. The CS-IR paradigms were originally developed with the recognition that any instrumental learning experiment inherently contains the elements of a classical conditioning procedure (e.g., Hilgard, 1937; Hull, 1930, 1931, 1934; Mowrer, 1947, 1960). Specifically, the reinforcer is also an US for a constellation of USs, and the reinforcer always occurs in the context of antecedent stimuli, one or more of which could become a CS. A variety of "CR-mediational" theories have evolved which assume not only that CRs are acquired in a collateral fashion during instrumental conditioning but also that the stimulus consequences of these hypothetical CRs serve as reinforcers, motivators, and/or cues for instrumental behavior (e.g., Amsel, 1958; Gormezano and Kehoe, 1975, 1981; Hull, 1930, 1931, 1934; Konorski, 1967; Logan and Wagner, 1965; Mowrer, 1947, 1960; Overmier and Lawry, 1979).

In testing CR-mediational theories, the CS-IR paradigms provide an elegant means for manipulating the classical conditioning parameters, and presumably the strength of the covert CRs, without becoming entangled in the complexities of identifying which of the many candidates represents an actual mediating CR. In fact, the CS-IR paradigms have revealed that interactions between the hypothetical CRs and the overt IRs are a good deal more complex than a unidirectional CR-IR interaction. Most notably, it appears that the covert CRs acquired during the explicit classical phase interact with other covert CRs, which are presumably acquired in a collateral fashion during initial instrumental training (Scavio, 1972; Trapold and Overmier, 1972). The apparent CR-CR-IR interactions have received substantial attention in recent theories predicated on the general assumption that conditioned appetitive and aversive motivational states summate in an algebraic fashion to affect overt instrumental behavior (Dickinson and Pearce, 1977; Konorski, 1967; Miller, 1963; Rescorla and Solomon, 1967). In addition to CR-IR and CR-CR interactions, there appear to be recursive influences of the IR on one or more of the CRs (IR-CR interactions), which have been indicated by findings that the outcome of classical-instrumental procedures can be altered dramatically by (a) the instrumental contingency schedule (e.g., Blackman, 1968; Overmier and Schwartzkopf, 1974), (b) the order of classical and instrumental training (e.g., Overmier and Seligman, 1967; Seligman and Maier, 1967), and (c) alterations in the effects of parameters of classical conditioning when it is administered in conjunction with instrumental training (e.g., Brackbill and Overmier, 1979; Scobie, 1972).

3. Instrumental Approach Behavior

Some instrumental procedures which entail the observation of an approach to food have been designated as "Pavlovian" because an explicit cue (CS) is presented and a hopper of food (grain or pellets), designated the US, is made available at a fixed time following the onset of the cue (e.g., Holland, 1977; Holland and Rescorla, 1975; Longo *et al.*, 1964). This procedure is identical to instrumental runway or maze procedures, particularly the goal box segment in which the food source is seen by the subject. As in the goal box, some approach behavior is necessary and, by definition, instrumental to actual receipt of the reinforcing agent/US. By confusing the availability and the presumed sight of food with receipt of the food (food in the mouth), the approach activity, usually measured grossly by stabilimetric devices, following availability of the food but before its receipt has been mistakenly identified as a UR. Although the development of anticipatory activity to the cue prior to food availability is undeniably associative, it is also undeniably an instrumental conditioning procedure with features distinct

from those of CS-CR conditioning. For studying basic associative processes, the usefulness of the instrumental approach procedures in examining such key variables as the interval between the intended cue and receipt of the reinforcer is limited by uncontrolled variation in the instrumental approach behavior cued by the sight of food.

4. Autoshaping

Autoshaping may tap basic associative processes in the same way as the CS-CR paradigms, but with one important and interesting exception: The acquired response is heterogeneous rather than homogeneous with respect to the US-UR. In the best examples, autoshaping consists typically of response-independent presentation of a lighted manipulandum (e.g., a lighted key) as a CS and proximal presentation of the US (e.g., water in the mouth), with the target response being contact with the manipulandum (e.g., key pecking). Where care has been taken to administer the US without requiring an IR, the acquired key-pecking response does not appear in the constellation of URs (Lucas *et al.*, 1979; Wasserman, 1973; Woodruff and Williams, 1976). The acquisition of a response in an effector system not affected by the US would qualify autoshaping as a new associative learning procedure arising from the stimulus presentations of the older CS-CR procedures, but with a response having the interesting property of stimulus antecedents which are to some degree separate from the US. As yet, the mechanism by which the responses, which are neither URs to the US nor instrumental to the reinforcer, are mobilized remains mysterious (cf. Woodruff and Williams, 1976).

5. A Comment

Although all the foregoing paradigms have an associative character, the class of behaviors conventionally used in each of them affects their suitability for investigations of not only basic associative processes but also the underlying neural substrate. In the CS-CR procedures, the class of behaviors studied has been an anatomically defined set of movements or secretions mediated by a relatively small group of muscles and/or glands. Consequently, the CS-CR procedures have allowed for the potential identification of neural final common pathway(s) for behavior. Moreover, since it is known in advance that responding in the target effector system will be elicited by the US, it has been possible to study the motor pathways of the responses prior to or in the absence of the conditioning trials. This situation permits the observation of changes in the activity of those pathways from the start of conditioning (cf. Thompson, 1976). In the other associative

paradigms, it is much more difficult to identify the final common pathways for the target behavior or to observe changes in them brought about by training, since the target response is usually outcome-defined (e.g., pressing the bar). A definition of a behavior in terms of its effects on the environment allows a wide variety of different body movements to yield the required outcome. Although an outcome definition may have utilitarian advantages and may approximate the way behavior is described in ordinary speech, the allowable variation makes it difficult, if not impossible, to identify clearly a final common pathway for the movements that make up the behavior. Moreover, since there is usually no known US for the target behaviors, their pathway cannot be identified outside the learning situation. This is not to say that instrumental conditioning or autoshaping cannot be done with discrete movements or secretions (anatomically defined behaviors), only that it has been rare and largely confined to instrumental avoidance procedures, e.g., leg flexion avoidance (Brogden, 1939; Wahlsten and Cole, 1972).

II. Mechanisms of Association and Reinforcement

Although associative doctrine has guided research with classical conditioning, early investigations revealed that the empirical laws of classical conditioning depart in important ways from a simple Law of Contiguity. In brief, it has been found that CR acquisition can reliably occur when the CS and US are temporally separated. This fundamental challenge to the Law of Contiguity was originally raised by Pavlov's discovery of "trace conditioning." A second challenge to a contiguity principle has been the observation that strict simultaneity between a CS and US yields little or no responding, while asynchronous presentation of the CS and US produces the most reliable CR acquisition (Bernstein, 1934; Kimble, 1947; McAllister, 1953). In addition to the problems of trace conditioning and stimulus asynchrony, the topographic characteristics of the behavioral CR have placed a burden on the conversion of associative doctrine to a scientific theory. Specifically, it has long been recognized that the form of the CR differs in many respects from that of the UR (e.g., Hilgard, 1936a,b). Most noticeably, the CR is initiated in advance of the US, rather than coinciding with the time of US application. Accordingly, this section will discuss the characteristics of trace conditioning, CS-US asynchrony, and CR topography in the rabbit NMR preparation, and what they have revealed regarding the fundamental mechanisms of associative learning.

A. TRACE CONDITIONING AND STIMULUS ASYNCHRONY

In trace conditioning, Pavlov (1927, p. 40) found that CR acquisition occurs even though the offset of the CS antedates that of the US, leaving an

"empty" interval between them. Furthermore, when the CR occurs, it is usually initiated in the interval after CS offset. Thus, there is no form of simultaneity between the CS and the US-UR, or between the CS and the CR. For Pavlov, the phenomenon of trace conditioning raised the awful specter of unsubstantial "psychic" causes underlying the apparent action at a distance. To bridge the gap between the CS and CR, Pavlov (1927) proposed that the CS event left a "trace," i.e., a perseverative representation in the central nervous system, and that the portion of the trace immediately antedating the CR was the effective instigator of the response. In addition to trace conditioning, as mentioned above, some degree of asynchrony rather than simultaneity between the CS and US appears to be necessary for CR acquisition to occur. Specifically, systematic manipulations of the CS-US interstimulus interval (ISI) in CS-CR paradigms have typically yielded concave ("inverted U")-shaped functions between CR frequency and ISI. At ISIs of zero or near-zero, responding to the CS is negligible; slightly longer ISIs produce dramatically higher levels of responding; and at even longer ISIs, a "contiguity gradient" appears in that the level of responding progressively diminishes across ISIs (cf. Gormezano and Moore, 1969, p. 136; Hall, 1976, pp. 111-115).

A joint demonstration of trace conditioning and stimulus asynchrony, using the rabbit NMR preparation, was conducted by Smith *et al.*, (1969). Specifically, the ISI manipulation included seven experimental groups ($n = 12$) receiving paired CS-US presentations at ISI values of 800, 400, 200, 100, 50, 0, and - 50 msec. In addition, a control group received unpaired presentations of CS-alone and US-alone. The CS was a 50-msec, 92-dB, 1000-Hz tone, and the US was a 50-msec, 4-mA, 60-Hz shock. With the brief CS, the ISI values longer than 50 msec constituted a trace-conditioning procedure. For each of eight acquisition sessions, the experimental groups received 80 paired CS-US trials, and the control group received 80 CS-alone and 80 US-alone trials. Furthermore, all groups received 21 CS-alone test trials daily with a fixed observation interval of 1 sec. Following acquisition, all subjects received one extinction session of 100 CS-alone trials.

Figure 5 presents the mean percentage of NMRs for all groups in daily blocks of 21 test trials in acquisition and blocks of 20 trials in extinction. The figure indicates that there was little evidence of pseudo-conditioning (Group C). Despite the large number of conditioning trials (640), there was no evidence of CR acquisition at the backward (- 50 msec), simultaneous (0 msec), and shortest forward (50 msec) intervals. In contrast, Groups 100, 200, 400, and 800 showed clear increases in percentage CRs and substantial responding in extinction. The Smith *et al.*, (1969) experiment is only one of an extensive series of rabbit NMR studies in which we have documented the effects of the CS-US interval (Gormezano, 1972; Kehoe, 1976, 1979; Kehoe *et al.*, 1981; Schneiderman and Gormezano, 1964; Schneiderman, 1966;

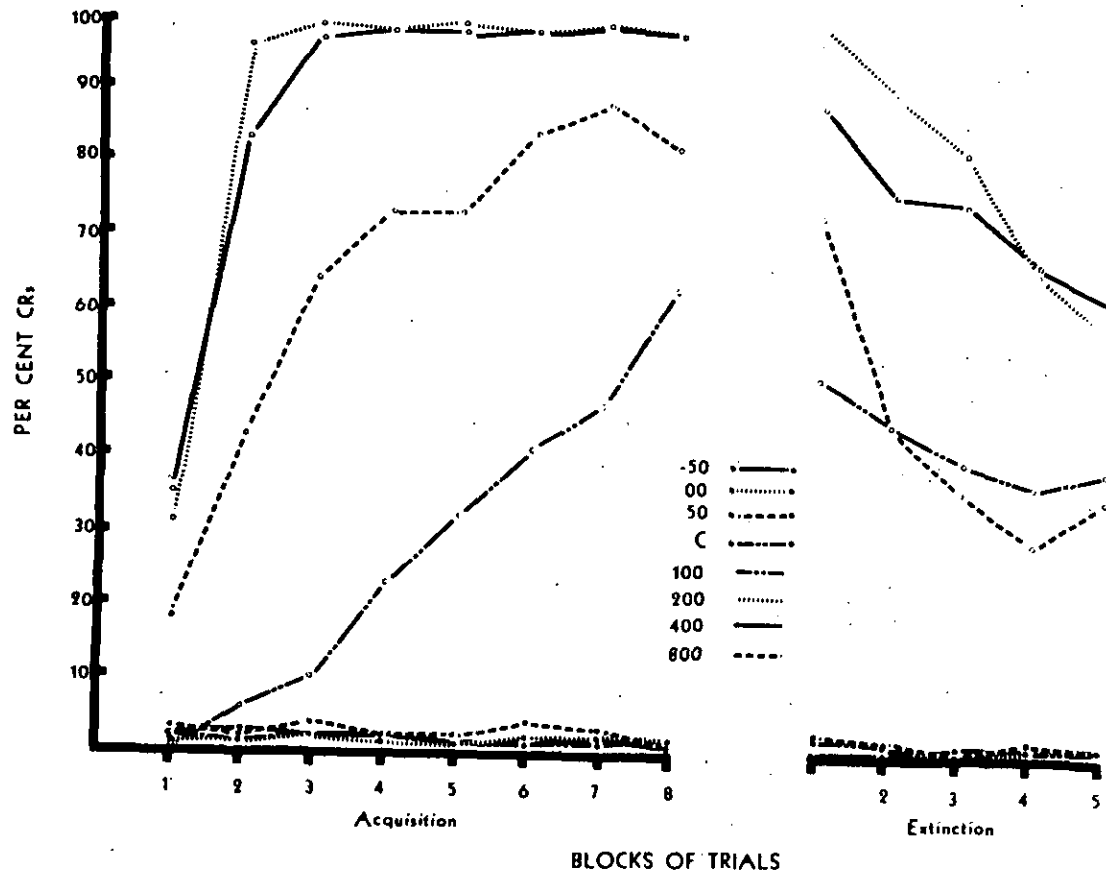


FIG. 5. The percentage of NMRs of all groups in blocks of 21 test trials (days) for acquisition and in blocks of 20 trials for extinction. (Smith *et al.*, 1969.)

Smith, 1968). Similar functions have also been obtained in delay conditioning, in which the CS duration fills the entire CS-US interval. Figure 6 summarizes the results of both the trace- and delay-conditioning studies by showing the mean CR percentage over all days of training. Inspection of Fig. 6 clearly reveals that a concave function describes the relation between ISI and CR frequency with a variety of additional conditioning parameters (e.g., US intensity).

In brief, the above NMR studies show that a CS-US interval of zero produces no CR acquisition but, as the CS-US interval approaches values between 200 and 400 msec, CR acquisition becomes increasingly rapid and reaches progressively higher asymptotic levels. However, CS-US intervals longer than 400 msec produce progressively lower rates and levels of acquisition. From inspection of the acquisition curves, some of which are shown in Fig. 5, it appears that the rate of CR acquisition is more sensitive to variations in the ISI than are asymptotic levels (Kehoe, 1976, 1979; Smith, 1968). For example, an 800-msec CS-US interval which produces only a modest

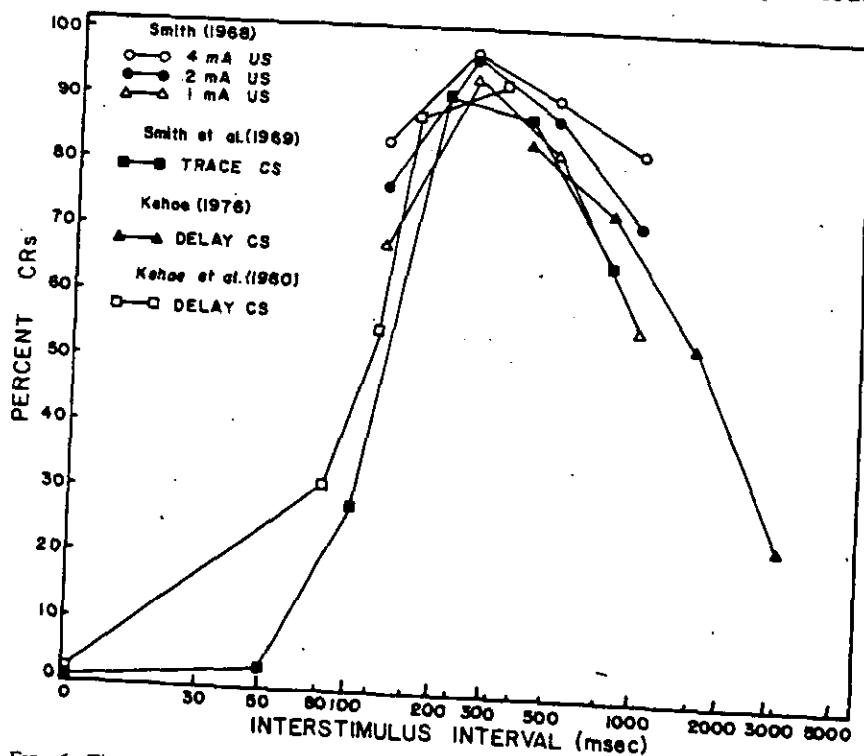


FIG. 6. The percentage of NMRs in acquisition as a function of the ISI in both trace and delay conditioning procedures.

rate of CR acquisition nevertheless, will ultimately produce asymptotic levels of responding near 100% CRs (Kehoe, 1976, 1979). However, longer CS-US intervals do produce asymptotic levels which are progressively less than 100% CRs (Schneiderman, 1966; Smith, 1968).

B. THE ANTICIPATORY RESPONSE

The most ubiquitous, and thus almost unnoticed, feature of CR acquisition is the anticipatory nature of the CR. In instrumental as well as classical conditioning, the acquired behavior has been observed to move forward in time to stimuli antedating the reinforcing event. Although the classical conditioning paradigm is regarded as providing an ideal vehicle for demonstrating the occurrence of anticipatory responses, detailed measurement of their quantitative characteristics has often been made difficult by the occurrence of baseline responses, alpha responses, and pseudo-conditioned responses. However, since contributions from these nonassociative sources are negligible in the rabbit NMR preparation, it has been possible to observe clearly the emergence of anticipatory CRs. In the NMR preparation, examination of CR latency data reveals that the first CRs are initiated just before the US, but then CR initiation rapidly shifts to progressively earlier portions of the CS-US interval. As asymptote, the frequency distribution of CR onset latencies is centered at about the midpoint of the CS-US interval, but with an increasing positive skew for longer CS-US intervals. For example, Fig. 7 shows the frequency histogram of latencies for the first CR (left panel) and the last CR (right panel) of 120 rabbits, all of which were trained with a 400-msec ISI. Unless one is willing to credit animals and humans with precognition, the anticipatory response must be tied to an interaction between the prior training history and some aspect of the stimulus conditions immediately antedating the observed response. For deducing the systematic decrease in CR latency which constitutes a primary quantitative feature of the anticipatory CR, trace accounts, as will be detailed below, have provided insight into the processes governing the emergence of the anticipatory CR (Gormezano, 1972; cf. Hull, 1943, 1952).

C. CS TRACE HYPOTHESES

Attempts to account for stimulus asynchrony and trace conditioning originated with Pavlov's (1927, pp. 39-40) proposal that the CS event leaves a perseverative trace in the central nervous system. Subsequent accounts have followed Pavlov's lead by postulating hypothetical stimuli which bridge the gap between the nominal CS and the US-UR (Anderson, 1959; Gormezano, 1972; Guthrie, 1930, 1933, 1935; Hull, 1937, 1943, 1952).

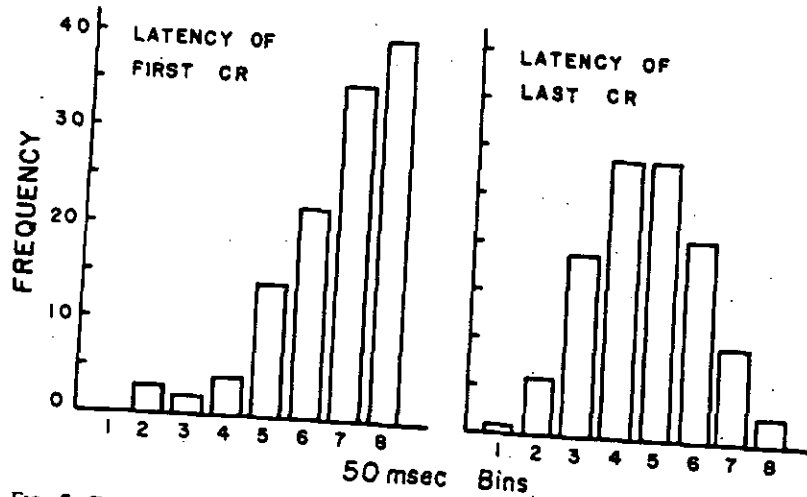


FIG. 7. Frequency histograms for onset latency of the first CR and the last CR in bins of 50 msec for a 400-msec ISI ($n = 120$).

Furthermore, all trace hypotheses have maintained that an association is formed through the strictly simultaneous occurrence of the effective CS (i.e., a portion of the trace) with the US-UR. Although the trace accounts manage to retain the Law of Contiguity, they do so at the cost of postulating hypothetical stimuli which are not identical in their time course to the objective CS. Nevertheless, in research with the rabbit conditioning preparations, the trace hypothesis has served as a heuristic guide in generating a considerable body of data, which, in turn, has provided indirect but converging evidence for some form of trace (Gormezano, 1972; Gormezano and Kehoe, 1981).

Recent CS trace accounts postulate that CS onset initiates a molar stimulus trace which rises in intensity to a maximum some time after CS onset and then gradually decays back to a null value (Gormezano, 1972; Hull, 1943). Associative strength is presumed to accrue at the point of contiguity between the CS trace and US-UR initiation, and the increment in associative strength on each trial is presumed to be a direct function of the intensity of the CS trace at the point of contiguity with the US-UR. Thus, the largest increments in associative strength would result from training with those forward CS-US intervals for which the CS trace is at a high or maximum intensity at the time of the US-UR. At shorter or longer CS-US intervals, the CS trace is too weak (or altogether absent) to be able to produce appreciable increments in associative strength. Consequently, the form of the empirical ISI-CR frequency function is postulated to reflect the variation in the intensity of the CS trace over time. To explain the occurrence of an-

ticipatory CRs, trace formulations assume that anticipatory CRs result from generalization along the intensity dimension from the point of CS trace and US-UR contiguity to earlier portions of the trace (Gormezano, 1972; Hull, 1943, 1952). Moreover, as associative strength at the point of contiguity increases, generalization would be expected to extend further along the intensity dimension and, accordingly, the CS trace. Thus, the CS trace hypothesis correctly predicts that the first CRs occur near the US, after which the mean CR latency decreases toward the onset of the CS (Gormezano *et al.*, 1962; Schneiderman, 1966; Schneiderman and Gormezano, 1964; Smith, 1968; Smith *et al.*, 1969).

1. *The CS Trace as a Behavioral Construct*

Although the concept of the stimulus trace has carried sensory and neurophysiological connotations, the form and characteristics of the trace are actually behavioral constructs defined in a given preparation under a given set of conditions (Gormezano, 1972; Gormezano and Kehoe, 1981). A case-by-case behavioral anchoring of the trace has been necessary since the divergence in ISI-CR frequency functions dashed early hopes that their form would be invariant over species and response systems (cf. Gormezano and Moore, 1969, pp. 135-138; Hall, 1976, p. 110). For example in the rabbit preparations, the ISI-CR frequency functions for the JMR and heart rate systems are substantially broader and may even have different optimal values than the function for the NMR preparation (Gormezano, 1972; Schneiderman, 1972). Since these divergences in ISI effects occur in the same species, it is clear that the neural counterparts of the CS trace construct lie only partly in the sensory system. For example, divergences in the ISI-CR frequency functions across response systems may arise, in part, from unavoidable differences in the definition of a single response occurrence. In the NMR preparation, the response is, in fact, a discrete, uniphasic behavior which occurs against a "quiet" background of low spontaneous responding and negligible contributions from nonassociative sources. In contrast, the JMR is a prolonged, multiphasic behavior which is affected to some degree by nonassociative processes (Gormezano, 1972, p. 169). In even greater contrast, the heart rate response is actually a specified change in a tonic, multiphasic behavior.

2. *Converging Evidence for the CS Trace*

a. *CR Peak Latency.* Although CR acquisition is characterized by the progressively earlier initiation of the target response, the CR should not be construed as a fixed pattern that is triggered by the CS. Instead, examination

of CR topography reveals orderly but diverse changes throughout acquisition. Whereas CR onset latency decreases, the maximal response amplitude, the CR peak, tends to be located around the time of US-UR occurrence (Coleman and Gormezano, 1971; Gormezano, 1972; Millenson *et al.*, 1977; Smith, 1968). For example, Fig. 8 shows the mean CR topographies obtained on CS-alone test trials by Smith (1968) for a factorial combination of four different ISI values (125, 250, 500, and 1000 msec) and three US intensities (1, 2, and 4 mA). Examination of Fig. 8 reveals that, across all conditions, the temporal peak of otherwise diverse-looking CRs is centered on the point at which the US occurred on reinforced trials.

In further support of the trace hypotheses, the location of the CR peak follows the point of CS trace-US contiguity quite closely. When the CS-US interval was altered, Coleman and Gormezano (1971) found that the CR peak at the original temporal locus of the US disappeared, and a peak appeared at the new temporal locus of the US. Similarly, when CS-US pairings were conducted with two randomly mixed ISI values, the CR topography showed two distinct peaks located at the points at which the US occurred. Millenson *et al.* (1977) varied the proportion of two ISIs (200 and 700 msec) across five groups, which were designated in terms of their proportion of 200-msec ISI trials. Three mixed ISI groups, labeled P7/8, P1/2, and P1/8 received, respectively, seven-eighths, one-half and one-eighth of 90 daily paired trials at the 200-msec ISIs and their remaining paired trials at the 700-msec ISI. Each mixed ISI group also received five 200-msec and five 700-msec CS-alone test trials. In addition, there were two fixed ISI groups. One, labeled 200F, received all its trials at the 200-msec ISI, and the other group labeled 700F, received all its trials at the 700-msec ISI. Figure 9 presents mean CR topographies for each group on days 3 and 10 under each test trial CS duration. Under the 700-msec CS duration (right panel), two of the mixed ISI groups, P7/8 and P1/2, developed pronounced double peaks located around the 200- and 700-msec points after CS onset. The other mixed ISI group, P1/8, showed only a slight "shoulder" at approximately 200 msec after CS onset and a distinct peak at around 700 msec after CS onset. Under the 200-msec test CS duration (left panel), peaks appeared at 200 msec but not 700 msec. The absence of the later peak on 200-msec test trials suggests that response performance is modulated, moment by moment, by the ongoing characteristics of the CS.

At a minimum, the placement of CR peaks around the temporal locus of the US may be regarded as evidence of a timing mechanism which precisely controls the response topography and could be based on a CS trace (Gormezano, 1972; Patterson, 1970). A stronger interpretation, which accounts for the precise characteristics of the CR topography for the NMR, contends that the momentary CR amplitude is a direct function of general-

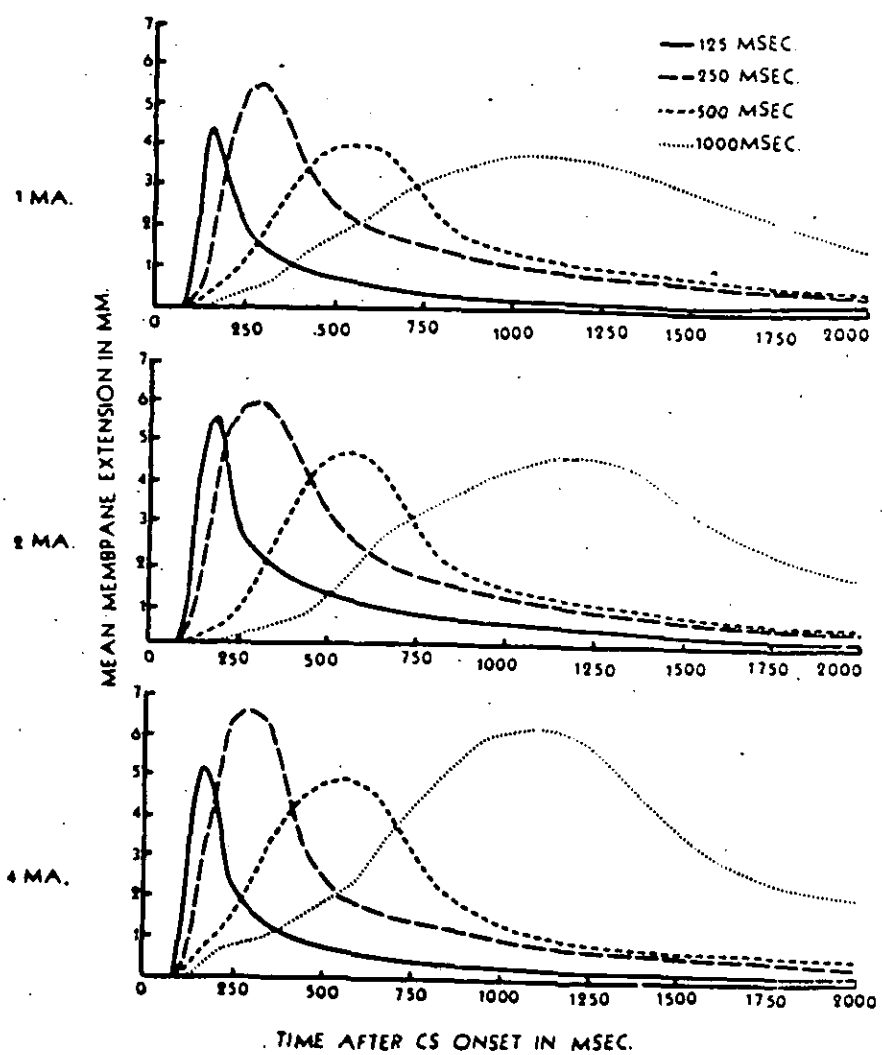


FIG. 8. The mean topography of NMRs based on five test trials on day 10. The mean membrane extension in millimeters as a function of time after CS onset in milliseconds is presented for groups receiving US intensities of 1 mA (top panel), 2 mA (middle panel), and 4 mA (bottom panel), with the ISI as the parameter. (Smith, 1968.)

ized associative strength at the corresponding point on the CS trace. Accordingly, the CR's maximal amplitude would be at the point(s) of maximal associative strength, which for CS trace accounts occur at the point(s) of contiguity between the CS trace and the US-UR (Gormezano and Kehoe, 1981).

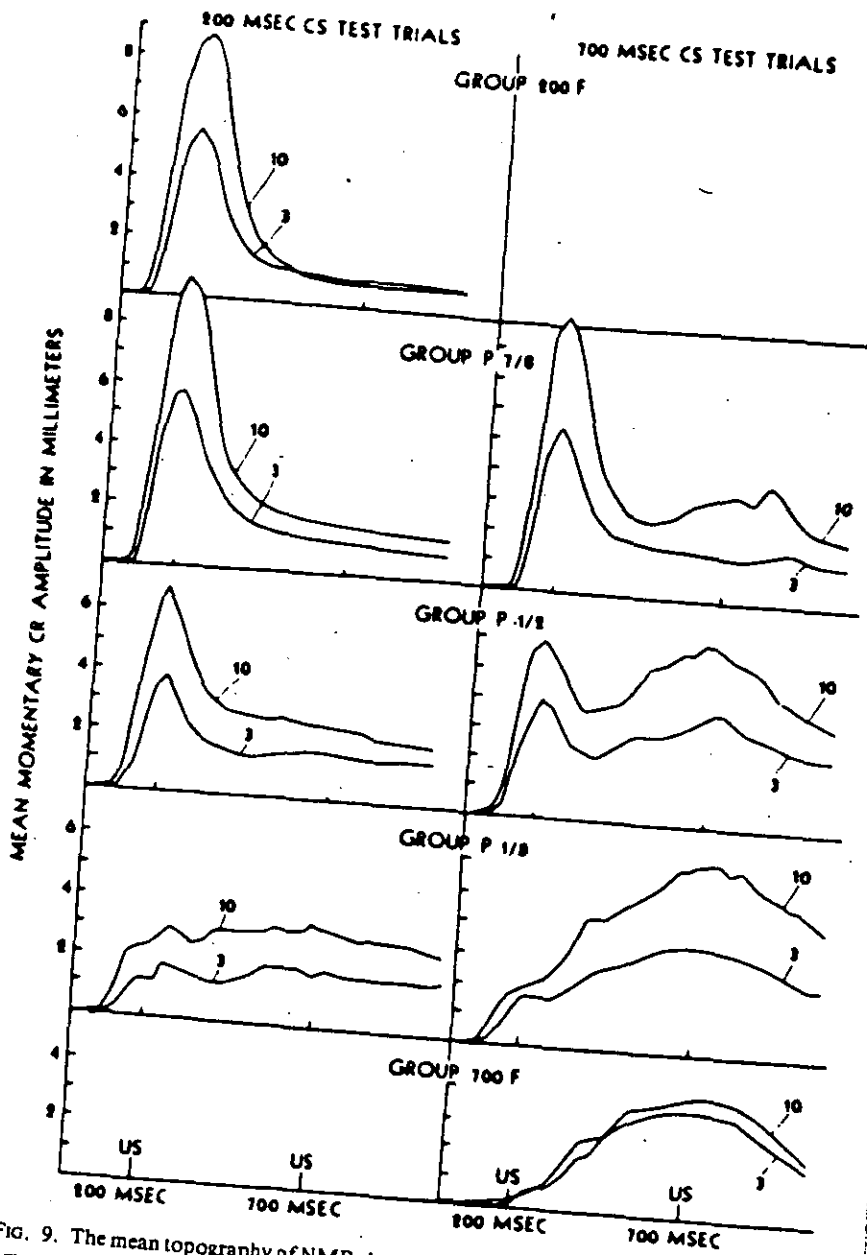


FIG. 9. The mean topography of NMRs based on five test trials on days 3 and 10 for 200- and 700-msec tests CS durations. The mean membrane extension in millimeters is presented as a function of CS onset in milliseconds. (Millenson *et al.*, 1977.)

b. Properties of the CS. The initial attempts to manipulate the CS trace were guided by Hull's conceptual appeal to the rate of neural firings as the physical basis for the intensity of the neural trace. Accordingly, a series of experiments were conducted using manipulations of the CS that might be expected to affect the frequency of neural firings. For instance, through activation of on-off fibers, intermittent stimuli should generate a greater number of neural firings contiguous with the UR to produce more effective conditioning. By the same token, the offset of a stimulus should, by itself, produce a brief train of neural firings and, hence, a weaker trace relative to the onset of a delay CS. In agreement with the expectations from Hull's formulation, a pulsed-tone CS produced faster CR acquisition than a constant CS, and the offset of a tonal stimulus present during the intertrial interval (ITI) produced slower conditioning than the same tone in a delay conditioning procedure (Gormezano, 1972, pp. 156-158; cf. Liu and Moore, 1969). Similarly, trace conditioning, in which the CS is brief, produces slower CR acquisition than delay conditioning (Schneiderman, 1966). In further agreement with Hull's trace hypothesis, CR acquisition in the NMR preparation is a direct function of the intensity of a tone CS over the range 65-86 dB (Gormezano, 1972, pp. 157-159; Scavio and Gormezano, 1974).

c. Intracranial Stimulation. Patterson (1970) has been able to manipulate the time course of the trace by using electrical stimulation of the rabbit's inferior colliculus as a CS. Such a stimulus, which bypasses a portion of the afferent system, should reduce the initial recruitment time of the CS trace and, thereby, foreshorten the minimal ISI necessary for conditioning. In fact, Patterson (1970) obtained a substantial level of responding at an ISI of 50 msec, a value which yielded no evidence of conditioning when a tone CS was used by Smith *et al.* (1969). Patterson's findings cannot be attributed to a greater dynamogenic effect of the intracranial CS relative to the tone CS used by Smith *et al.* (1969) because, at an ISI of 400 msec, the intensity of Patterson's intracranial CS was one that had been empirically demonstrated to support a lower level of responding than the tone CS.

d. ISI-UR Amplitude Functions. An even more promising means of behaviorally anchoring the form of the trace may be found in the ISI-UR amplitude ("CS excitability") function for reflex modification in the NMR preparation (Ison and Leonard, 1971; Thompson, 1976). In the ISI-UR amplitude modification procedure, animals are presented with threshold-intensity USs preceded by a tone or light CS at various ISIs. The total number of CS-US trials is restricted to preclude the appearance of CRs which would obscure the URs. In general, it has been found that the UR amplitude varies as a function of the ISI, and in terms of the CS trace hypothesis, the effects of the CS on the UR can be construed as reflecting the inherent dynamogenic effects of CS trace intensity at the time of UR occur-

rence. Figure 10 shows, as a function of the ISI, the mean change in UR amplitude from the baseline UR amplitude to the US-alone. Inspection of the figure indicates that the form of the ISI-UR amplitude generally agrees with the concave ISI-CR frequency functions (cf. Smith *et al.*, 1969). In particular, the ISIs of 0 and 50 msec failed to augment UR amplitude. On the other hand, ISIs of 100-800 msec produced progressively larger URs, and longer ISIs produced a progressive decline in the amplitude of augmentation. In comparison to ISI-CR frequency functions, the maximum ISI-UR amplitude function is displaced toward the value of 800 msec, which produces only a modest rate of CR acquisition (cf. Kehoe, 1976; Smith *et al.*, 1969). However, Thompson (1976) has obtained an ISI-UR amplitude function which more closely duplicates the ISI-CR frequency functions for the NMR preparation. In view of the parallels between ISI effects on CR acquisition and UR amplitude, it is possible to anchor the trace independently of conditioning and to predict the ISI-CR frequency function.

D. CONTINGENCY FORMULATIONS AND THE "TRULY RANDOM" CONTROL

Since the inception of our research with rabbit preparations, unpaired presentations of the CS and US have been used to obtain a joint estimate of nonassociative contributions to responding (Schneiderman *et al.*, 1962). The unpaired procedure evolved from earlier independent assessments of nonassociative contributors based on CS-alone (e.g., Hilgard, 1931) and US-alone procedures (e.g., Grant, 1943). Guided by contiguity principles, the

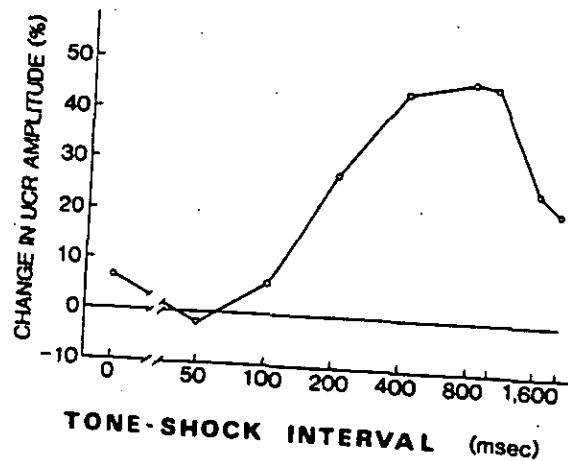


FIG. 10. The mean percentage change in UCR amplitude as a function of the tone-shock interval.

unpaired procedure entailed the randomized sequencing of the CS and US and long intervals between stimulus events to minimize the operation of any CS-US contiguity effects. In the late 1960s, contiguity-based associative theory and its control methodology came into question when several theorists considered the possibility that associative learning could be reconceptualized in molar terms, in which the statistical relation between the CS and US is the fundamental determinant of response acquisition (cf. Gormezano and Kehoe, 1981; Prokasy, 1965; Rachlin, 1976, pp. 80-86, 190-192; Rescorla, 1967). Most notably, Rescorla (1967) proposed a contingency hypothesis which focused on the degree to which the CS "predicts" or carries "information" about the US, as specified in terms of the relative frequency or probability of US occurrence in the presence and absence of the CS. Furthermore, the contingency hypothesis assumed that there are symmetric excitatory and inhibitory associative contributions to responding to the CS arising from CS and US presentations. Specifically, if the probability of a US is greater in the presence of the CS than in its absence, a "positive contingency" would prevail and "excitatory" associative effects would accrue to the CS. Conversely, "inhibitory" associative effects would presumably accrue if the probability of a US were higher in the absence of the CS than in its presence, thus yielding a "negative contingency." Accordingly, an unpaired control condition, in which there is a perfect negative contingency, was expected to be inhibitory in its consequences. To provide an associatively neutral condition in which to assess inhibitory as well as excitatory conditioning, Rescorla (1967) proposed the "truly random control," which was variously specified in terms of independent programming of the CS and US (p. 74) or, more precisely, in terms of equal probabilities of US occurrence in the presence and absence of the CS (p. 76).

As a first step in discussing the contingency-contiguity controversy, it must be recognized that all descriptions of interstimulus relationships, whether CS-US contingency or contiguity, are conventional shorthand notations which draw attention to theoretically important features of the sequence of events to which the animal is exposed. A classical conditioning procedure, taken by itself without theoretical preconceptions, consists of predetermined stimulus presentations and certain types of response measurements (cf. Gormezano and Kehoe, 1975; Hilgard, 1937). On the stimulus side, any session of classical conditioning can be comprehensively described by the duration of events and the intervals between successive events, as is typically done in connection with the actual programming of control apparatus. The occurrences of each type of event, i.e., CS and US, can be described separately with respect to a common reference point at the start of the session. As a concrete example, the separate event-marker lines for the CS and US traced on a polygraph chart constitute a complete record

of events presented to an organism under study. Any relationship of contingency or pairing can be seen to be abstraction of this record.

Although both CS-US pairing and contingency describe features of the sequence of stimulus durations and ISIs in a classical conditioning session, the precise specification of pairing/unpairing or the value of a contingency for a given preparation cannot be arrived at through *a priori* arguments; it relies on extensive empirical knowledge as well as the record of events. At a minimum, the distinction between pairing and unpairing of a CS and a US relies on a delineation of the empirical effects of CS-US interval manipulations. Although contingency hypotheses are couched in terms of the statistical relations between the CS and the US, the operational implementation of the truly random control must acknowledge CS-US interval effects to identify what constitutes the effective presence or absence of the CS at the time of US occurrence.

In the contiguity-contingency controversy, one important set of facts concerning the unpaired control has been continually obscured: In many CS-CR preparations, the unpaired procedure frequently produces substantial levels of responding to the CS, which hardly implies the acquisition of an inhibitory potential. In fact, it was the responding produced by the CS-alone and US-alone procedures which led to the development of the unpaired control as a means for estimating the cumulative contribution of nonassociative excitatory processes (Gormezano and Kehoe, 1975). Whereas (as detailed previously) the NMR preparation displays no evidence of non-associative contributions, the JMR preparation can show substantial levels of nonassociative responding (Mitchell and Gormezano, 1970; Sheafor, 1975; Sheafor and Gormezano, 1972). For example, Sheafor and Gormezano (1972) manipulated the magnitude of the water US across the values of 1, 5, and 20 cc and examined its effect on the JMR in paired and unpaired conditions. In the paired condition, the CS-US interval was 500 msec, whereas in the unpaired condition, the CS and US were each presented once per day in random order, with a minimum interval of 4 min between them. Figure 11 shows the percentage measures of JMRs during the CS and a pre-CS period as a function of 5-day blocks (one trial per day) in both acquisition and extinction. For all three US magnitudes, the level of responding to the CS was higher in the paired than in the unpaired condition. Nevertheless, responding in the unpaired condition was appreciable and was positively related to US magnitude. Moreover, the excitatory effects of the unpaired procedure persisted into extinction, in which all presentations of the US were suspended. Throughout training, baseline responding during the pre-CS period remained at a low level, thus controlling for any general "arousal" produced by US presentations. In brief, the unpaired procedure in the JMR preparation, as well as other CS-CR preparations (e.g., human eye blink),

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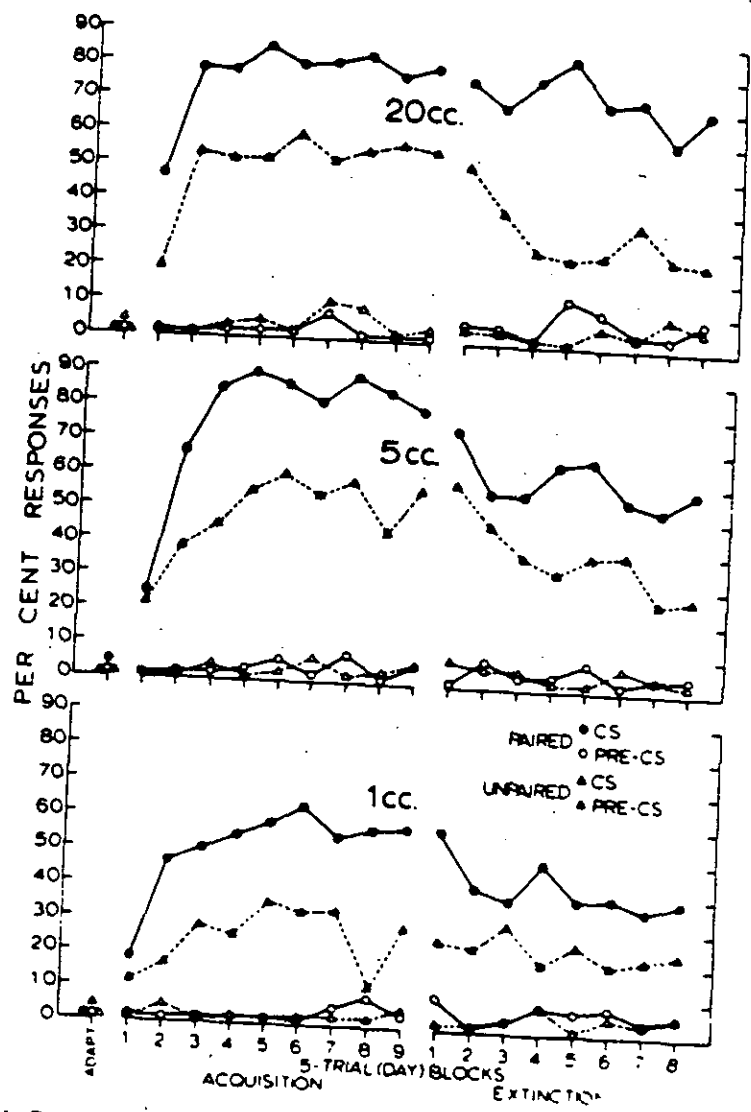


FIG. 11. Percentage of JMRs during CS and pre-CS periods as a function of five-trial (day) blocks in acquisition and extinction. (Sheafor and Gormezano, 1972.)

has hardly had the suppressive effect that the contingency formulation would lead one to expect. In the case of these preparations, the use of a truly random control, which allows chance pairings of the CS and US, would produce even higher levels of responding to the CS, which would largely mask the consequences of the systematic CS-US pairings in the paired condition.

Of course, a committed contingency theorist could reverse the argument and contend that the excitatory nonassociative processes mask the inhibitory associative processes in the unpaired condition. If the unpaired procedure does have an inhibitory effect, it should be readily apparent in the NMR preparation, in which the unpaired procedure yields only baseline levels of responding. Accordingly, Holmes (1971), as part of a larger set of experiments, compared the effects of four "control" conditions—no stimulation, explicitly unpaired, truly random and US-alone—on subsequent CR acquisition under paired CS-US training in which the CS-US were programmed independently of one another, such that the likelihood of a chance conjunction of the CS and US within a 4-sec time unit was 0.004. In the CR acquisition transfer test, it was found that the no-stimulation group showed a significantly higher level of responding (51%) than the unpaired (19%), truly random (22%), and US-alone (23%) groups, which failed to differ significantly from one another. Since the US-alone group showed a level of performance similar to that of the unpaired and truly random groups, it may be concluded that the difference between the no-stimulation group and the remaining groups arises from the US presentations in the first stage and not from any associative consequences of the contingency between the CS and US presentations. Subsequently, the decremental effect of US-alone presentations has been confirmed in the rabbit NMR preparation (Mis and Moore, 1973) and subjected to scrutiny in other CS-CR and CS-IR procedures (Randich and LoLordo, 1979). A variety of associative and nonassociative accounts of the decremental effects of prior US exposure have been considered, but this set has not included the contingency formulations (cf. Randich and LoLordo, 1979).

In summary, it appears that the associative methodology embodied in the unpaired control is entirely appropriate for assessing the contributions to responding made by excitatory nonassociative processes. Where the contiguity-based associative methodology has indicated negligible nonassociative contributions, as in the NMR, there is no evidence of acquired inhibitory effects arising from a negative contingency between the CS and the US. However, this is not to say that there are no processes for the acquisition of inhibitory potential to the CS has been obtained in the NMR using Pavlov's (1927) conditioned inhibition paradigm. In the paradigm, one CS—CS (A)—is paired with the US when by itself but not when compounded with a second CS—CS (X). As a result, CS (X) acquires the ability to inhibit responding to otherwise excitatory stimuli (Marchant *et al.*, 1972). In Pavlov's view, the acquisition of inhibition was dependent upon the prior acquisition of excitatory strength through CS-US pairings. Thus, whereas the dimension of excitatory and inhibitory strength is perfectly symmetric, the acquisition processes are asymmetric. As formalized by Rescorla and

Wagner (1972), the acquisition of excitatory strength is achieved through CS-US contiguity, but the acquisition of inhibitory strength by a stimulus can take place only when there is extinction of the excitatory strength of a concurrent stimulus.

E. BIDIRECTIONAL AND BACKWARD CONDITIONING

1. Bidirectional Conditioning

Although the most robust conditioning occurs with forward CS-US presentations, there has been a persistent interest in the use and effects of backward US-CS presentations. Beritov (1924) and, subsequently, Pavlov (1932) and his successors in the Soviet Union (e.g., Asratian, 1952, 1966) have regarded backward procedures as a means for investigating the bidirectional nature of associative connections between two stimuli (see Gormezano and Tait, 1976; Razran, 1971; Tait, 1974). Specifically, the bidirectional conditioning hypothesis is based upon a neural model which assumes that bidirectional (forward and backward) connections are formed in both classical and instrumental conditioning situations. In classical conditioning, it is assumed that during the traditional pairings of the CS and US, discrete cortical areas are activated and two independent connections are formed. One connection, a forward connection, is presumed to traverse a pathway from the cortical representation of the CS to that of the US, whereas a backward connection is assumed to run from the US "center" to the CS "center." At the behavioral level, subsequent to the formation of the connections the presentation of either stimulus is expected to elicit the response corresponding to the other stimulus. In theory, bidirectional conditioning is presumed to occur under all pairing operations and, hence, with the pairing of two CSs (i.e., sensory preconditioning), a US followed by a CS (i.e., backward conditioning), and two USs. However, because of its greater analytical power, the paradigm involving the pairing of two USs is commonly employed by the more active Russian investigators in their studies of bidirectional conditioning. In the US_1 - US_2 pairing operation, two responses, UR_1 and UR_2 , can be readily observed; accordingly, the paradigm permits concurrent examination of the development of both forward and backward conditioning (connections). Forward conditioning is revealed by the anticipatory occurrence of " UR_2 " (forward CR) to US_1 (forward CS), whereas backward conditioning is shown by the occurrence of " UR_1 " (backward CR) on test trial presentations of US_2 alone (backward CS). Consequently, the paradigm of pairing two USs has the methodological virtue of permitting the behavioral assessment of the purported formation of both forward and backward connections within the subjects.

To determine whether bidirectional conditioning occurs in the US_1 - US_2 paradigm, two rabbit investigations have been conducted involving an oral injection of a water US paired with either a corneal air puff (Gormezano and Tait, 1976) or a paraorbital shock US (Tait, 1974). Thus, it was possible to measure both the JMR and the NMR. The order of stimulus pairings was counterbalanced, and evidence for forward and backward associative learning was assessed against the performance of groups receiving unpaired presentations of the two USs. When water-air puff and air puff-water pairings were used, forward conditioning was clearly obtained, but the response to the backward stimulus (US_2 - UR_1) did not differ from the level obtained in the unpaired controls (Gormezano and Tait, 1976). When shock-water pairings were used, some indication of the NMR backward conditioning was obtained: In water test trials, NMRs showed (a) a smaller number of trials to the first NMR CR relative to the unpaired group and (b) an initial but temporary increase in the percentage of responses over the consistently low level shown by the unpaired group. With water-shock pairings, it was not possible to make a clear determination of forward JMR conditioning because shock reliably evoked a small unconditioned JMR. However, some indication of backward conditioning of the JMR to shock was detected: The frequency of responses and their amplitude showed small but significant increases in the shock-water group but not in the unpaired group. Consequently, the safest assessment of the empirical status of the bidirectional conditioning hypothesis is that under the US_1 - US_2 paradigm, if backward associations exist, their behavioral manifestations are much weaker and more difficult to detect than associations based on forward stimulus pairings.

2. Backward Conditioning

In the tradition of Western associationism, the backward pairing procedure has been used to test a variety of conflicting conceptions regarding the nature of associative connections. Thus, under backward US-CS pairings, some contiguity theories predict excitatory associative effects symmetric with those obtained with forward CS-US pairings (Guthrie, 1933; Jones, 1962), whereas stimulus trace theories have predicted no associative effects (Gormezano, 1972; Hull, 1943, 1952), and contingency theories have predicted the acquisition of an inhibitory effect resulting from the long US-free interval which follows the CS (Prokasy, 1965; Rescorla, 1967; Wagner and Rescorla, 1972). Evidence for incremental effects of backward pairings has been obtained in studies with the human galvanic skin response (Champion, 1962; Champion and Jones, 1961; Jones, 1961; Trapold *et al.*, 1964; Zeiner and Grings, 1968). However, the susceptibility of the GSR to

augmentation by nonassociative processes (Gormezano, 1966; Stewart *et al.*, 1961; Venables and Martin, 1967) severely lessens the confidence that can be placed in the data. In animal studies using classical-instrumental (CS-IR) paradigms, in which the consequences of stimulus pairings are measured by the facilitory or disruptive effects of presenting the nominal CS during instrumental (operant) responding, the results of backward pairings have yielded both excitatory (Heth and Rescorla, 1973; Matsumiya, 1960; Mowrer and Aikens, 1954) and inhibitory effects (see Kamin, 1963, for criticism of Singh's study; Moscovitch and Lólordo, 1968; Siegal and Domjan, 1971, Experiment 1; Singh, 1959).

In research with the rabbit NMR preparation, the results have largely indicated that backward presentations of a shock US and a tone CS produce no consistent effects (Holmes, 1971; Smith *et al.*, 1969). In these investigations, a variety of procedures have been used to detect excitatory and inhibitory effects of backward pairings. Specifically, Smith *et al.*'s (1969) investigation of the ISI-CR frequency function included one group in which the 50-msec US immediately preceded the onset of a 50-msec tone CS. Test trials and extinction with CS-alone presentations yielded a mean level of responding of less than 2%. Subsequently, Holmes (1971) examined two different classical conditioning transfer procedures. In the first paradigm, Stage I consisted of backward pairings or control treatments and Stage II of transfer testing with forward pairings with a 250-msec ISI. Transfer testing revealed that four different backward US-CS intervals (50, 500, 5000, and 10,000 msec) produced a lower rate of CR acquisition than a group which had received no stimulus presentations during Stage I. However, the apparent retardation did not differ from that of other control groups which received unpaired stimulus presentations, truly random stimulus presentations, or US-alone presentations. Evidence obtained with a rabbit eye blink preparation (Siegal and Domjan, 1971) suggests that a greater number of backward pairings (495) may produce a retardation relative to a truly random control. However, since Siegal and Domjan's truly random control contained several forward CS-US pairings, an excitatory contribution from these pairings may have produced the difference between the backward group and the truly random group (cf. Ayres *et al.*, 1975).

Whereas transfer from backward to forward pairings has yielded ambiguous results, Holmes found that transfer from forward to backward pairings has yielded evidence that backward pairings slowed extinction of the CR established during forward pairings. In Stage I, all groups received training with forward CS-US pairings such that all group means exceeded 95% CRs. In Stage II, different groups received either backward pairings at US-CS intervals of 50, 500, 5000, or 10,000 msec, explicitly unpaired stimulus presentations, truly random stimulus presentations, or CS-alone presentations

(i.e., extinction). It was found that the groups receiving 50 and 500 msec backward US-CS presentations showed a higher level of responding than all the other groups. On the one hand, the relatively high levels of responding in the backward groups may indicate that backward pairings have a weak excitatory effect capable of maintaining an already established forward connection. On the other hand, Holmes noted that the presentation of the US prior to the CS at the 50- and 500-msec intervals may "mask" (perceptually obscure) the CS, thus protecting the CS from extinction.

F. MECHANISMS OF REINFORCEMENT

Despite the persistent identification of classical conditioning with association through contiguity (Robinson, 1932), the mechanism of reinforcement for the CR remains a subject of continued debate (Coleman and Gormezano, 1979; Gormezano and Kehoe, 1975, pp. 166-172; Kimmel and Burns, 1975). Empirically, the US-UR complex is responsible for the acquisition and maintenance of a CR. In fact, it was Pavlov (1927, p. 49) who coined the term "reinforcement" to designate the crucial role of the unconditioned reflex in conditioning. However, the mechanism by which the US-UR provides a reinforcing state of affairs remains unclear. The two principal theoretical accounts have been contiguity and effect formulations. In contiguity accounts (e.g., Estes, 1959; Guthrie, 1930, 1952; Sheffield, 1965), the role of the US is presumed to ensure the occurrence of the UR in an appropriate temporal relationship to the CS, whereas effect theories hold that the US must also have motivational consequences. Effect theorists have made numerous proposals regarding the character of the motivational consequences arising from the US. These proposals may be divided into two broad classes based on whether CR acquisition is determined (a) by the presumed motivational properties of US occurrence *per se* or (b) through CR-produced modification of the sensory consequences of the US.

1. *The Law of Contiguity and Thorndike's Law of Effect*

Contiguity accounts and US effect accounts differ only in regard to whether any motivational consequences of the US are necessary to CR acquisition and maintenance. In its most elementary form, a contiguity account argues that the necessary and sufficient condition for a CS-CR association is the co-occurrence of the designated stimulus and response (UR). In this basic contiguity formulation, the US simply provides the means for the experimenter to evoke the target response (UR) in the presence of the CS. Likewise, the Law of Effect as originally formulated by Thorndike

(1913) is first and foremost a principle of association through stimulus-response contiguity. The relevant portion of the law states, "Of the several responses made to the same situation, those which are accompanied or closely followed by satisfaction to the animal will, other things being equal, be more firmly connected with the situation so that, when it recurs, they will be more likely to recur" (p.). Thus, Thorndike's Law of Effect focused on the "connection" (association) between "situations" (stimuli) and "responses" in exactly the same manner as the Law of Contiguity. The distinguishing mark of Thorndike's Law of Effect is that it required the contiguity of three events—situation, response, and satisfier—for the formation of an association. Nevertheless, the only members of the association were the situation and the response; satisfaction served as a necessary catalyst to the formation of the association without itself being a member. Although the Law of Effect was formulated in connection with what has since been recognized as instrumental conditioning, it should be clear that, like the Law of Contiguity, it does not restrict the means by which contiguity of events occurs. Thus, the Law of Effect can and has been applied without modification to classical conditioning (e.g., Hull, 1943). Under this law as applied to classical conditioning, the US serves as the source of both the response and the necessary motivational satisfaction. With the response-motivation contiguity assured by the US, the pairing of the CS with the US-UR is all that is experimentally necessary to establish a CS-CR association. Thorndike's Law of Effect has been adopted by a number of theorists, who have differed primarily over the nature of the motivational catalyst provided by the US (e.g., Hull, 1943; Konorski, 1967; Miller, 1963; Mowrer, 1960; Spence, 1956). Using the basic contiguity and effect formulations as guides, an extensive series of experiments has been conducted with the NMR preparation to delineate the characteristics of the US which govern conditioning.

Frequent attempts have been made to distinguish between contiguity and effect hypotheses by discovering a stimulus which reliably evokes a UR but does not ostensibly have motivational consequences (Loucks, 1935; Loucks and Gantt, 1938; Young, 1958). Under such circumstances, contiguity theory predicts that CR acquisition would occur, whereas effect theory predicts that it would not (Brogden, 1962; Kimble, 1961, p. 214). However, there are no conventional criteria for identifying motivational properties of a stimulus independent of a learning situation. Historically, Thorndike objectively tied the hedonistic satisfying and annoying qualities of an event to the approach or evasive behavior evoked by the event in question (Hilgard, 1948). Unfortunately, all too often it appears that identification of an event's motivational properties relies on an anthropomorphic reconstruction of the subjective pleasure or pain produced by the event. Although ambiguities in the definition of "motivation" make it difficult to reject an ef-

fect account of any instance of learning, it is possible to doubt the sufficiency of S-R contiguity any time that a US-UR constellation fails to produce conditioning. In the rabbit NMR preparation, some characteristics of the US beyond its response-evoking capacity appear to be required to produce CR acquisition. Specifically, CR acquisition has been routinely obtained with both paraorbital shock and corneal air puff USs, but not with a strong light which reliably evoked a UR (Bruner, 1964). Specifically, Bruner (1963) compared the effectiveness of a modest air puff US (an 80-mm puff of compressed nitrogen) and a light US (a 200-watt incandescent lamp). Across 700 CS-US trials, the air puff US produced an asymptotic level of approximately 80% CRs, whereas the light US produced no increase over the base rate of 2% responses. Clearly, these results suggest that S-R contiguity is insufficient to produce CR acquisition. Conversely, these results yield tentative support for an effect formulation, although the motivational property possessed by an air puff and not an intense light remains to be identified.

Using both contiguity and effect formulations as heuristic guides, we have gone on to examine the effects produced by the manipulation of the intensity and duration of a paraorbital shock US on CR acquisition. According to contiguity hypotheses, anything which increases the "vigor" (e.g., amplitude and duration) of the UR will increase the likelihood of the target response. Whereas contiguity theory is clear in its predictions regarding US parameters, effect formulations differ dramatically in their expectations regarding US variables. Thus, according to Hull's "drive-reduction" version of Thorndike's Law of Effect, the onset of an aversive US induces a "drive" state, as well as evoking the target response. However, reinforcement of the S-R association does not occur until drive is reduced by the offset of the US. Hence, increases in US intensity would increase the drive level and, accordingly, the magnitude of drive reduction at the time of offset. However, increases in US duration would delay the time of drive reduction, thus reducing its contiguity with the CS and UR. Consequently, increases in US duration would be expected to have an inverse effect on the rate of CR acquisition (Miller, 1963, pp. 73-75; Mowrer, 1951, 1960). In summary, contiguity and drive-reduction formulations largely agree in their predictions regarding US intensity while differing with respect to US duration. However, virtually complete convergence between contiguity and effect formulations can be obtained with those effect formulations which maintain that reinforcement of an S-R association occurs at the point of "drive induction," i.e., US onset (Mowrer, 1960).

Empirically, investigations which manipulated US intensity and duration have yielded results which have largely supported contiguity/drive-induction rather than drive-reduction formulations. Specifically, US intensity has a strong positive effect on the rate of CR acquisition in the NMR preparation

(Ashton, *et al.*, 1969; A. Smith, 1966; M. Smith, 1968). As shown in Fig. 6, Smith (1968) found that a 50-msec shock US at intensities of 1, 2, and 4 mA produced progressively higher overall levels of responding, with the largest effects appearing at the longer ISIs. As required by contiguity formulations, recent examinations of the shock-NMR unconditioned reflex reveal that there is a positive effect of US intensity on UR vigor as indexed by UR magnitude, a measure which averages together the amplitude of observed responses and zeros for instances in which a UR failed to occur. For the 1-, 2-, and 4-mA values used by Smith (1968), the mean UR magnitudes are approximately 3.0, 6.0, and 8.5 mm of nictitating membrane extension.

In further agreement with contiguity/drive-induction hypotheses, the rate of CR acquisition is a positive function of the US duration (Ashton *et al.*, 1969; Tait *et al.*, 1981). In a differential conditioning procedure, Ashton *et al.* (1969) compared the effects of a 50- and a 350-msec US duration. They found that the 350-msec US duration increased the mean level of responding to CS+ by approximately 10 percentage points while having no differential effect on the low level of responding to CS-. The difference between US durations was obtained across US intensity values of 0.5, 2.0, and 4.0 mA. Similarly, Tait *et al.* (1981, Experiment 1) found that the mean number of trials before the first CR for US durations of 50, 1500, and 6000 msec was 99, 67, and 52, respectively. (The lower the number of trials, the faster the rate of CR acquisition.) Although the 6000-msec US duration produced the most rapid initial CR acquisition, it also produced pronounced decrements in responding within each session. These within-session decrements, together with the prolonged UR produced by the long US, suggested that a "fatigue-like" performance factor may have had a deleterious effect on CR performance. Subsequently, Tait *et al.* (1981, Experiment 4) equated groups for total US exposure by using US-alone presentations interpolated between CS-US pairings. Thus, a group receiving a 50-msec US on paired trials was administered a 6000-msec US during the intertrial interval. When the potential contribution of performance factors was controlled, the rate of CR acquisition, as indexed by the percentage CR measure, was a positive function of the US duration. As an alternative to controlling the contribution of performance factors, Tait *et al.* (1981, Experiment 5) conducted training using only one trial per daily session. Presumably, the 24-hour interval between successive trials would be sufficient to permit the total dissipation of any energizing or fatigue effect of the prior US presentation. Again, the CR percentage measure was a positive function of US duration.

2. Instrumental Interpretations

In its most general form, the instrumental "law of effect" hypothesis contends that a CR is acquired because it is capable of so affecting the stimulus

consequences of the US that execution of a CR is "rewarding" relative to a failure to make a CR. Specifically, CR-US overlap is presumed to attenuate the noxiousness of an aversive US or to enhance the "attractiveness" of the appetitive US. Thus, a hypothetical instrumental contingency is postulated to be embedded intrinsically in classical conditioning procedures. Historically, the instrumental interpretation of classical conditioning can be traced to a strong but nonlogical identification of the Law of Effect with instrumental conditioning procedures as laboratory models of adaptive behavior (see Coleman and Gormezano, 1979; Gormezano and Coleman, 1973; Gormezano and Kehoe, 1975, pp. 168-172; Hull, 1929; Schlosberg, 1937; Skinner, 1938).

a. Laboratory Models of Adaptation. Pavlov viewed the conditioned reflex as the basic unit by which an animal's behavior would be adjusted to correspond to the exigencies of its particular environment (Pavlov, 1927, pp. 15-17, 395; see Coleman and Gormezano, 1979). In Pavlov's conception of behavioral adaptation, conditioning mechanisms are fixed in any individual member of a species and are adaptive only in the sense that they, being physically based on the nervous system, are the product of the Darwinian laws of variation and natural selection. Thus, through evolution, conditioning mechanisms are adaptive insofar as they have contributed to the survival of the species. However, conditioning mechanisms do not ensure that an individual member of a species will necessarily behave in the most appropriate manner in a particular situation. Conceivably, conditioning mechanisms could operate to produce self-destruction of an individual if unusual circumstances arose. In summary, mechanisms of conditioning do not guarantee that behavioral adjustment will occur in all cases, only in enough cases to ensure survival of the species. In Pavlov's concept of adaptation, the primary principle of individual adjustment is that of "signalization," whereby stimuli antedating biologically significant events come to evoke anticipatory responses in the organism in preparation for those events (Donahoe and Wessells, 1980, pp. 17-20.).

The instrumental interpretation of classical conditioning arises from a concept of adaptation which stresses the individual's "success" in each situation (Schlosberg, 1937), an approach which is most clearly exemplified in Skinner's (1937, 1938) views of instrumental conditioning. The Pavlovian model emphasizes stimulus determinants of behavior, whereas Skinner has emphasized the consequences of an animal's acts as the determinants of subsequent behavior. The individual animal is viewed as both a provider and an evader of biologically significant events which are most suitable in each particular situation. In stressing the relation between a behavioral act and its subsequent consequences, Skinner reformulated the effect principle in terms of the experimental arranged instrumental contingency between the target

response and an empirically reinforcing event. In a similar fashion, Schlosberg's (1937) criterion for the application of the Law of Effect was the instrumental nature of a response. Consequently, effect principles in general became identified with instrumental procedures, even though Thorndike's (and Hull's) Law of Effect does not refer to the experimental procedure by which a stimulus, response, and reinforcer are brought together. In this historical context, instrumental interpretations of classical conditioning can be seen as an attempt to assimilate classical conditioning in a situation-specific model of adaptation.

Schlosberg (1937) offered what appears to be the first instrumental effect interpretation of classical conditioning, although it was couched as a methodological device for determining whether experiments carried out ostensibly by classical conditioning had, in fact, administered the US in a manner independently of the CR. A CR found to modify the reception of the US would be said to reflect not only the laws of Pavlovian conditioning but also the Law of Effect, tied as it was to instrumental conditioning. By an imaginative reconstruction of the possible consequences of a CR for receipt of the US, Schlosberg reasoned that, for example, the eyelid CR may avoid the air puff, the knee jerk CR may decrease the stimulating value of the tap on the tendon, and the salivary CR may enhance the stimulating value of a dry meat powder US. Thus, Schlosberg's interpretation of conditioned reflex preparations hypothesized an intrinsic causal relationship between the CR and its presumed situationally adaptive outcome by which the sensory consequences of the US are altered. These alterations were alleged by Schlosberg to act as "intrinsic reinforcers" for the CR. However, this allegation was not supported by any experimental demonstration that increases in CR strength depend on CR modification of the US, nor were operations provided for determining when CRs did, in fact, modify the sensory properties of the US.

b. Research Strategies. Because criteria for determining the presence of CR modification of the US and its presumed reinforcing consequences wait upon operational specification, no procedure has been proposed for deciding unequivocally the legitimacy of an instrumental interpretation in any particular classical conditioning preparation. However, various reconstructions of the situationally adaptive consequences of CRs have been readily produced by such theories. Nevertheless, as yet, no procedure exists which simultaneously permits the manipulation of CR-US overlap and adherence to classical conditioning's procedural requirement that the US be delivered independently of the CR. Hence, an intrinsic CR-US overlap reinforcement contingency cannot be given a procedural specification similar to that of an extrinsic experimenter-arranged instrumental contingency. Given the lacking of such a procedural specification, two research strategies have been pursued to assess the plausibility of instrumental interpretations of classical conditioning.

Response-contingent alterations of US intensity. First, attempts have been made to determine the reinforcing effects of CR-produced US attenuation in aversive conditioning through the use of explicit response-contingent alterations in US intensity, thus making completely extrinsic the presumed relation between the CR and its effects upon US sensory consequences. Although the introduction of such a contingency would designate the paradigm as one of instrumental conditioning, it would not constitute a confounding of the procedural and theoretical distinctions under consideration, since such a procedure would bring under experimental control what has been the speculative source of reinforcement in classical conditioning by instrumental "law of effect" accounts. Accordingly, Coleman (1975), using the NMR preparation, examined the effects of CR-contingent decrements in the amperage of a shock US. The standard US was a constant-current 100-msec, 5-mA, 60-Hz shock delivered to the paraorbital region, and the CS was a 500-msec tone. There were four groups of subjects, all of which received the 5-mA shock if a CR did not occur on a trial. The subjects in Groups 5-0, 5-1, and 5-3 received the 5-mA US if no CR occurred, but when a CR did occur, they received a reduction in the US intensity to the values of 0, 1.7, and 3.3 mA, respectively. The subjects in Group 5-5 received the same 5-mA US whether a CR occurred or not and, accordingly, served as a conventional classical conditioning group. A plot of the frequency of CRs on 6 days of training is presented in Fig. 12. It is apparent from examination of the figure that except for Group 5-0, the separation among groups is not large. However, there was a significant increasing linear trend across the overall mean percentage of CRs for Groups 5-0, 5-1, 5-3, and 5-5. In a second experiment, Coleman (1975) used three groups, each exposed to a standard shock of 3 mA when no CR occurred. On CR trials for one group, there was an increase in the US to 5 mA (Group 3-5), for another the shock was maintained at 3 mA (Group 3-3), and for the third group the US was reduced to 1 mA (Group 3-1). In agreement with the results of the first experiment, the level of performance across the three groups was ordered with respect to the shock-US intensity with the mean percentage of CRs for Groups 3-1, 3-3, and 3-5 being 71%, 80%, and 85%, respectively.

The observation in both experiments that percentage CRs decreased with a contingent decrease in US intensity is inconsistent with expectations from an instrumental interpretation of classical conditioning. Instrumental effect hypotheses contend that reduction by the CR of the noxious sensory consequences of the US is a source of response-contingent reinforcement in classical conditioning. The observed decrease in percentage CRs with CR-contingent reductions in shock intensity is, thus, in a direction opposite to that expected from the instrumental effect hypotheses. Minimally, Coleman's findings indicate that a *reduction* in the physical intensity of the US was not a reinforcing state of affairs.

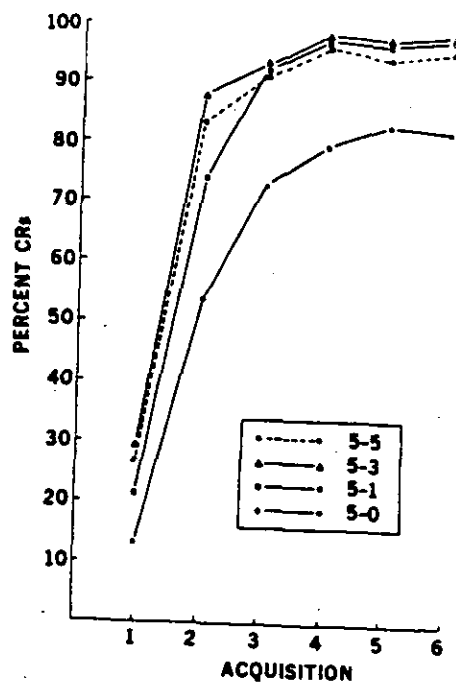


FIG. 12. Percentage NMRs to the CS plotted in blocks of 80 trials for each day of acquisition (Gormezano and Coleman, 1973).

An instrumental-effect theorist could argue that reinforcement arises solely from the intrinsic CR-US overlap, as opposed to an experimenter-imposed contingency. However, in Coleman's (1975) findings, the substantial level of CR acquisition seen in Group 5-0 provides contradictory evidence, since in that group there was never CR-US overlap, the postulated source of reinforcement. In a similar fashion, Gormezano and Coleman (1973) found that acquisition of a JMR to a stable asymptote of 60% CRs would occur even when there was a CR-contingent omission of the water US, again precluding CR-US overlap. Moreover, from the perspective of an instrumental-effect hypothesis, the acquisition of a CR under the omission schedule is highly maladaptive in the situational sense, for it produces a reduction in the frequency of reward. However, from the perspective of the Thorndike/Hull Law of Effect, CR acquisition under an omission procedure is not the least surprising. Specifically, reinforcement of the CS-JMR association occurs on the CS-US-UR trials, whereas the CS-CR trials (without the US) have extinctive effects equivalent to those of a CS-alone presentation on a partial reinforcement schedule.

Response shaping by CR-US overlap. The second major tactic for assessing instrumental-effect hypotheses has grown out of the "response-shaping" formulations of the basic instrumental interpretation of CR acquisition (Boneau, 1958; Kimmel, 1965; Kimmel and Burns, 1975; Prokasy, 1965). Through the operation of the CR-US overlap reinforcement mechanism, CRs with quantitatively different topographical features are regarded by response-shaping formulations as constituting separate response classes. Moreover, through the operation of a response-correlated reinforcement mechanism (cf. Logan, 1956), each class is assumed to be differentially reinforced in proportion to the degree of CR-US overlap that it produces. Accordingly, there have been persistent examinations of CR topography in search of features which tend to coincide with the point of US occurrence and, thus, could be regarded as indicants of the operations of a CR-US overlap reinforcement mechanism. For the rabbit NMR preparation, the temporal characteristics of the CR peak amplitude correspond, in a descriptive sense, to the desired properties of an index of a response class subject to a CR-US overlap reinforcement mechanism. Specifically, the peak of the NM CR tends to coincide with the temporal loci of the US under fixed ISIs (Smith, 1968), shifted ISIs (Coleman and Gormezano, 1971), and mixed ISIs (Millenson *et al.*, 1977).

Although response-shaping formulations have been useful in directing attention to CR topography, they possess no means for predicting which CR measures will reflect the presumed operation of the response-correlated reinforcement mechanism. In the absence of a precise definition of a CR-US overlap indicant, response-shaping theorists have had to rely on *post hoc* determinations of the correspondence between expectations of their formulation and any given CR measure. Thus, the tenability of response-shaping formulations is vulnerable to any arbitrary measure which fails to be correlated with the time of the US. Most notably, in the rabbit NMR preparation, the initiation of the CR, as measured by CR latency, decreases systematically away from the US toward CS onset, rather than assuming some relatively fixed position near US onset. In an attempt to account for decreases in CR latency, Martin and Levey (1969, p. 93) have asserted that CR latency decreases "in the service of changes in amplitude which adjust the response more closely to the UCS/UCR complex." Thus, they are maintaining the CR latency is only indirectly subject to differential reinforcement through CR-CS overlap. However, Martin and Levey (1969) do not specify the functional relationship between CR latency and any indirect indicant of CR-US overlap, nor how CR latency would change as a function of independent variable manipulations. More generally, Martin and Levey's account and any other account which maintains that a CR measure is, for example, a secondary consequence of the directly reinforced CR (e.g., muscular tens-

ing) still provides no means for predicting whether a given CR feature in a given experimental situation would be a direct indicant of CR overlap or would be serving in an ancillary capacity.

III. Manipulations with Multiple CSs

Although the thrust of research with the NMR preparation has been directed at questions concerning the fundamental variables of classical conditioning and associative learning (e.g., CS-US interval, CS duration, CS intensity), a wide variety of experiments have been conducted to address wider issues of attention, perception, and expectancy. Empirically, these experiments have entailed the paradigms of discrimination, generalization, and compound conditioning, in which the contrast and blending or multiple CSs have been found to exert a powerful influence on behavior.

A. DISCRIMINATION AND GENERALIZATION

The study of generalization and discrimination has provided an objective basis for the delineation of the sensory/psychophysical capabilities of nonverbal animals (Pavlov, 1927, p. 111). Moreover, it has long been recognized that the transfer of responding which characterizes stimulus generalization is crucial to the adaptive economy of the animal, because environmental situations never recur in nature without changes. By the same token, the selective responding which characterizes discrimination learning represents a corrective to any excesses produced by the generalization process (Hilgard and Marquis, 1940, pp. 176-177).

In the rabbit NMR preparation, extensive studies of discrimination and generalization along the dimension of tone frequency have been carried out by Moore and his associates (Ashton *et al.*, 1969; Chisholm *et al.*, 1969; Hupka, *et al.*, 1969; Liu and Moore, 1969; Moore, 1972; O'Malley *et al.*, 1969). Studies with tone intensity have been conducted by Moore (1972) and Scavio and Gormezano (1974). In addition to studies with single sensory dimensions, conditional discriminations and patterning procedures have been used as means for investigating the perceptual processes by which animals integrate stimuli from multiple dimensions and/or modalities (Blough, 1972; Chase and Heinemann, 1972; Kehoe and Gormezano, 1980; Pavlov, 1927, p. 144; Saavedra, 1975; Wickens, 1954, 1959, 1973). "Patterning" entails the differential reinforcement of a compound and its components. In positive patterning, reinforced presentations of, say, a tone-light compound (TL+) are intermixed with unreinforced presentations of the separate components (T- and L-), whereas in negative patterning, unreinforced compound presentations (TL-) are mixed with reinforced com-

ponent presentations (T+ and L+). "Conditional discriminations" entail differential reinforcement of different compounds which share at least one component.

An example of a conditional discrimination in the NMR preparation has been demonstrated recently by Marshall *et al.* (1980). In their experiment, rabbits were exposed to two serial compounds consisting of a tone-light sequence and a noise-light series. One compound was always paired with the US (A-X+) and the other compound was presented alone (B-X-). The particular assignment of tone-light and noise-light serial compounds to the A-X+ and B-X- conditions was counterbalanced across subjects. Rabbits were assigned to six groups ($n = 12$) which resulted from the orthogonal combination of three durations of the first stimulus (400, 600, and 800 msec) and two durations of the second stimulus (100 and 400 msec). The ISI between the first and second CS was fixed at 900 msec, and the ISI between the second CS and the US was fixed at 400 msec. Each of 20 daily sessions included 30 A-X+ trials and 30 B-X- trials, plus two nonreinforced test trials of A-X, A, B, and X.

The rabbits showed clear evidence of differential responding to the compounds as a whole. Across all groups, responding to A-X+ reached mean levels above 90%, whereas performance to B-X- reached a considerably lower level, averaging about 50%. In addition, the use of the serial compound procedure permitted examination of responding to the individual elements of the compound as well as the compound as a whole. Of most interest, responding to the common light element X showed differentiation depending on whether it was preceded by A, B, or nothing at all. Figure 13 shows the percent CRs to X on A-X+, B-X-, and X-alone test trials across 10 2-day blocks. The performance curves represent the average of all six groups. Inspection of the figure reveals that responding to X when preceded by A, which signaled an impending US, showed systematic increases to a mean level of 54% at the termination of the experiment, but when preceded by the nonreinforced B, responding to X reached a mean level of only 33% CRs midway through training and then began to show some declines. This differential responding to X demonstrated that responding to one stimulus can be made conditional on another or, in the case of the serial compound, on the aftereffects of another stimulus. Moreover, responding to X was even lower when presented by itself, which suggests that there was some degree of stimulus generalization between the aftereffects of the tone and noise used as the A and B stimuli. The apparent confusability between the aftereffects of A and B has permitted us to employ differential conditioning with serial compounds to examine not only the perceptual integration of complex stimuli but also to assess the psychophysical and memorial properties of stimulus traces.

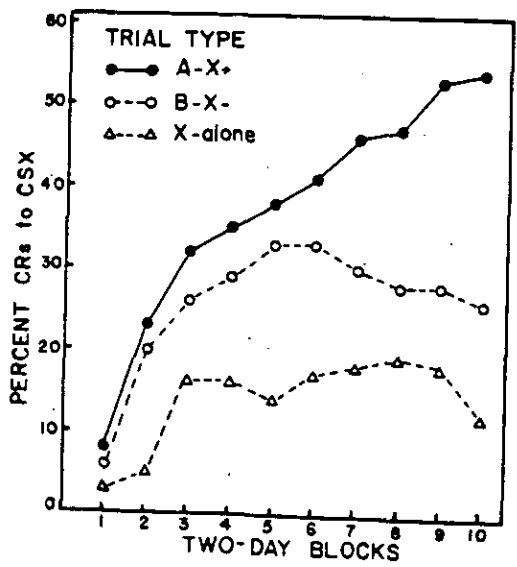


FIG. 13. Percentage NMRs to CSX (the second stimulus) on A-X+, B-X-, and X-alone trials plotted as a function of two-day blocks of trials. (Marshall *et al.*, 1980.)

B. COMPOUND STIMULUS CONDITIONING

Any animal in even the most sterile environment is faced with a continual and multifaceted stream of stimulus events. To discover the laws governing behavioral adjustments to the exigencies of an environment, Pavlov (1927, pp. 110-113) and subsequent investigators used compounds of separable stimuli as a laboratory model for the array of innocuous events which antedate a biologically significant stimulus (e.g., Hull, 1943; Kehoe and Gormezano, 1980; Razran, 1965, 1971; Wickens, 1954, 1959, 1965). More recently, investigations of NMR using relatively simple compounds of tone and light stimuli have revealed that an astonishing variety of processes affect CR acquisition in an environment of even modest complexity (Gibbs, 1979; Gormezano and Kehoe, 1981, 1982; Kehoe *et al.*, 1979, 1981b).

In any compound stimulus-conditioning procedure, it is possible to examine not only the integration of the stimuli which make up a compound but also the interactions among stimuli. Logically, there are two types of interactions: negative interactions, in which CR acquisition is impaired by training to a compound stimulus, and positive interactions, in which CR acquisition of the target CR is facilitated by compound stimulus training. The study of negative interactions has been motivated by the repeated recognition that not every pair of contiguous events appears to become associated (Brown, 1920, pp. 199-214; Gormezano and Kehoe, 1981; Kamin, 1968, 1969; Lashley,

1929, 1942; Rudy and Wagner, 1975). This apparent selectivity in the formation of associations has been investigated under the headings of "stimulus selection" "selective attention" and "compound-to-component generalization" (Dickinson and Mackintosh, 1978; Kamin, 1969; Kehoe, 1979; Mackintosh, 1975; Riley and Leith, 1976, Rudy and Wagner, 1975, pp. 270-272; Wickens, 1959, 1965). The study of positive interactions has been conducted with compounds containing the serial presentation of stimuli (CS1-CS2). Serial compounds have produced CR acquisition to CSs long antedating a US, i.e., CSs located beyond the bounds of CS-US contiguity as empirically described by the ISI-CR frequency function (Gibbs, 1979; Gormezano and Kehoe, 1981, 1982; Kehoe *et al.*, 1979). The positive interaction obtained in serial compounds has provided an empirical basis for those behavior theories which contend that covert CRs and their stimulus consequences mediate temporally extended instrumental behavior (e.g., maze learning, operant chains), in which complex sequences of behavior are initiated to stimuli which are temporally remote from the goal object (Hull, 1930, 1931, 1934; Konorski, 1948, 1967; Logan and Wagner, 1965; Mowrer, 1947, 1960). More generally, the concept of mediating CRs has been considered a behaviorally anchored analog to the mentalistic notion of "expectancies" as instigators of action based on past experience. Accordingly, the investigation of CR acquisition in serial compounds can be regarded as providing an objective counterpart to the principles governing the acquisition of expectancies.

1. Stimulus Selection.

a. Basic Phenomena. The design for detecting interactions has usually entailed fixing the training parameters for one target stimulus (X) while varying the parameters of another stimulus (A) in a compound. The level of responding to X observed on individual test trials outside the compound is then compared to the level of responding observed with corresponding groups trained with only X (Kehoe, 1979; Wickens, 1965). Using this general tactic, it has been found possible to impair CR acquisition to an otherwise effective X stimulus through manipulations of (a) the schedule of prior CSA-US pairings, (b) the CS-US interval of A, and (c) the relative intensity of A. The capacity of prior CSA-US training to impair CR acquisition to CSX during subsequent AX training has been labeled "blocking" (Kamin, 1968, 1969). The first demonstrations of blocking with the rabbit NMR preparation were conducted by Marchant and Moore (1973). Three experiments all contained two essential groups. The main group (A-AX) received CSA-US pairings until the level of responding reached 80-90% CRs. During the same stage, the second group (sit-AX) was exposed to handling and restraint in the

experimental chambers but was not exposed to either the CS or the US. Then, both groups received reinforced compound training with simultaneous presentations of A and X followed by the US. Finally, testing with X in extinction revealed a low level of responding to X in the A-AX group as compared to the sit-AX group. Since both groups had an equal number of AX training trials, the low level of responding to X in the A-AX group could not be solely attributed to any deleterious effect of compound training and/or generalization decrement arising from tests with CSX outside the compound.

Marchant and Moore (1973) went on to show that the blocking effect depended on prior training with CSA, for training of CSA following AX compound training (AX-A) yielded a high level of responding to CSX during final extinction testing. Furthermore, the blocking of CR acquisition to CSX depended on the compounding of A with X, because separate and successive training to CSA and CSX (A-X) yielded a high level of responding to CSX approaching that of a group which received only CSX-US training (sit-X). Additional investigations by Kehoe *et al.* (1981b) and Schreurs and Gormezano (1980) have described further details of the parameters of blocking.

Stimulus selection among serial stimuli (Egger and Miller, 1962; Wickens, 1959, 1965, 1973) has been obtained in the NMR preparation (Kehoe, 1979; Kehoe *et al.*, 1979). Specifically, CR acquisition to a CS relatively contiguous to the US may be impaired by a preceding stimulus which has a more remote temporal relation to the US. In the work of Kehoe *et al.* (1979, Experiment 1), the serial compound consisted of two components: CS1, a 400-msec 1000-Hz tone, and CS2, a 400-msec, a 20-Hz flashing houselight. In Experiment 1, the CS2-US interval was held constant at an efficacious interval of 350-msec, and the CS1-US interval was manipulated across the values of 750, 1250, 1750, and 2750 msec, respectively. Training was conducted for 16 days, each day consisting of 60 CS1-CS2-US trials interspersed with two test trials each of CS1, CS2, and CS1-CS2. Figure 14 depicts the mean percentage of CRs to CS1 and CS2 across blocks of four test trials. For expository purposes, the four groups are labeled in terms of the modality of CS1 (tone), the trace interval between CS1 offset and CS2 onset (0, .5, 1, and 2 sec), and the modality of CS2 (light). Thus, the groups were labeled T-O-L, T-.5-L, T-1-L, and T-2-L, respectively. Examination of the right-hand panel shows that, despite the constant 350-msec CS2-US interval, the rate of acquisition and the terminal level of CRs to CS2 were an inverse function of the CS1-US (and CS1-CS2) interval. In particular, Group T-O-L, which had the shortest CS1-US interval, showed slow CR acquisition to an asymptote of around 40% CRs. In a subsequent experiment, Kehoe *et al.* (1979, Experiment 2) replicated the low level of responding to

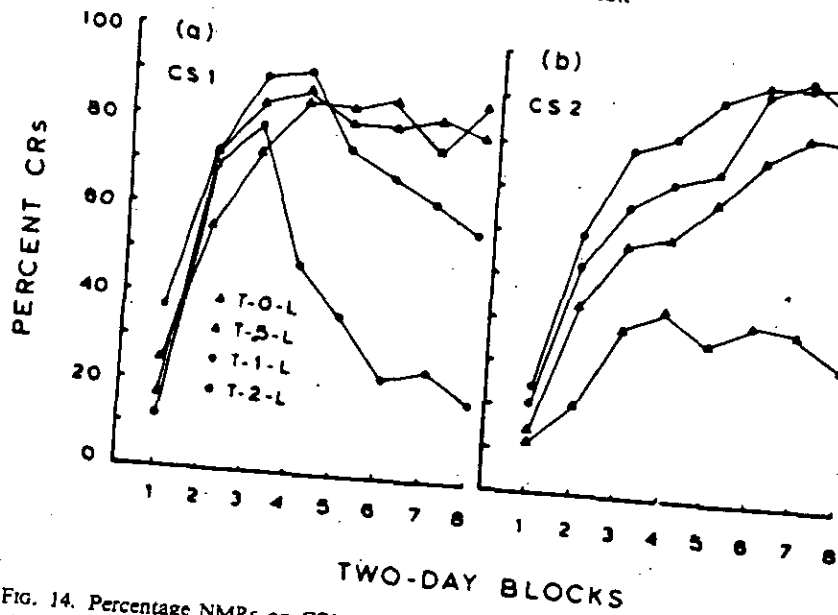


FIG. 14. Percentage NMRs on CS1 and CS2 test trials plotted as a function of two-day blocks. Groups T-0-L, T-0.5-L, T-1-L, and T-2-L are labeled in terms of the first component of the serial compound; the tone (T), the trace interval expressed in seconds (0, 0.5, 1, or 2), and the modality of the second component, light (L). (Kehoe *et al.*, 1979.)

CS2 in Group T-0-L and confirmed that it was significantly lower than the asymptote of 100% CRs obtained when the same CS was trained by itself at the 350-msec CS-US interval.

Examination of the left-hand panel of Fig. 14 indicates that despite the rather large differences in the CS1-US interval across groups, the acquisition of CRs to CS1 was at first rapid and uniform across groups. Moreover, all groups attained at least 80% CRs before the groups trained under the longer CS1-US intervals (Groups T-1-L and T-2-L) showed pronounced declines in performance. Later experiments confirmed that the high levels of responding to CS1 in the serial compound represented a substantial augmentation of CR acquisition relative to groups trained with a single CS at the same CS-US interval (Kehoe *et al.*, 1979, Experiments 2 and 3). A more detailed discussion of the augmentation of CRs to CS1 in a serial compound will be discussed below in the section on "Associative Transfer." In summary, the results of Kehoe *et al.* (1979) revealed a large impairment in CR acquisition to CS2 when the CS1-US interval (and thus the CS1-CS2 interval) was short. When the CS1-US interval was long, CR acquisition to CS2 was normal, but surprisingly, CR acquisition to CS1 was markedly facilitated.

The original demonstration of a stimulus selection phenomenon was con-

ducted by Pavlov (1927, p. 141) under the label of "overshadowing." Overshadowing is said to occur when the rate and level of CR acquisition to CSX are reduced through compound training with another relatively intense CSA (Kamin, 1969; Mackintosh, 1976). Kehoe (1981) has recently demonstrated overshadowing in the NMR preparation by using a visual CS (a 20-Hz flashing houselight) as X and varying the intensity of a tone CS as A in independent groups over values of 85, 89, and 93 db. During reinforced training with the compound, light-alone and tone-alone test trials were interspersed among the compound trials. In addition, single-stimulus control groups were trained with either the light or one of the tone intensity values. Overshadowing was demonstrated in that responding to the light in the groups trained with compounds containing the 89 and 93 db tones was significantly lower than the level of responding shown by the control group trained with only light. Across 6 days of training, the light-control group showed a mean level of 79% CRs, whereas the 85, 89, and 93-db compound groups showed mean levels of 82%, 47%, and 34% CRs, respectively, to the light. In the NMR preparation, overshadowing appeared to be unilateral in that the level of responding to the tone in all three compound groups was uniformly high and failed to differ from the levels obtained in the tone control groups. Specifically, the 85, 89, and 93-db compound groups displayed mean levels of 78%, 83%, and 85% CRs to the tone, whereas the corresponding tone control groups showed mean levels of 79%, 87%, and 75% CRs, respectively, to the tone.

b. Stimulus Selection Theory. The most well-developed accounts of stimulus selection phenomena include "attentional" theory (e.g., Mackintosh, 1975; Sutherland and Mackintosh, 1971) and "modified continuity" theory (Rescorla and Wagner, 1972). Although these two theories differ in many respects, their accounts of "selective association" have two common assumptions: (a) CS-US contiguity is necessary, i.e., the law of conditioning obtained with a single CS and US are applicable at all times; and (b) selective effects in compound conditioning result from competition between the concurrent CSs for attention or associative strength. Mackintosh (1975) has dispensed with the assumption that there is a strictly limited capacity for attention at any one time. Nevertheless, he has retained the proposition that there is a tradeoff in the degree of attention accruing to concurrent stimuli as a function of their relative associative strengths (Kehoe *et al.*, 1981b). Thus, blocking, serial stimulus selection, and overshadowing can all be explained by noting that CR acquisition to CSX suffers because of a competitive advantage which accrues to CSA through prior training, temporal primacy in a serial compound, and greater "saliency," respectively. Support for the competitive hypotheses has recently been obtained by Kehoe *et al.* (1981b), who found that blocking was still obtained even when CSX was more con-

tiguous to the US (ISI = 400 msec) than CSA (ISI = 800 msec), thus providing further evidence that the ordinary associative consequences of CS-US contiguity can be highly attenuated by processes of attention or competition for associative strength.

Although competition theories appear to describe the major mechanism underlying stimulus selection phenomena, Kehoe (1979) has found some evidence that a "recognition failure" or, more technically, a generalization decrement does operate to lower the level of responding to CSX. A generalization decrement hypothesis contends that associative strength acquired to a stimulus within the context of a compound fails to transfer completely to testing situations with a single CS outside the context of the compound (Borgeait *et al.*, 1972; Rescorla, 1972; Wickens, 1959, 1965, 1973). In support of a generalization decrement hypothesis, Kehoe (1979) found that responding to CS2 inside a serial compound attained higher levels than responding to the same CS2 outside the compound.

2. Associative Transfer

Kehoe *et al.* (1979) found that a serial compound (CS1-CS2-US) in which the CS2-US interval was 350 msec would substantially augment responding to a CS1 even when the CS1-US interval fell outside the bounds of the NMR contiguity gradient for a single CS-US pair. Specifically, at a CS-US interval of 2750 msec (see Group T-2-L in Fig. 14), responding to CS1 increased over the course of 6 days, or 360 reinforced compound trials, to a mean level of 80% before a gradual decline began to appear. Furthermore Kehoe *et al.* (1979, Experiment 3) found a similar pattern of acquisition followed by a decline at CS1-US intervals ranging over the values of 4750, 8750, and 18,750 msec, where the CS2-US interval remained at 350 msec. Thus, even when CS1 was located at CS1-US intervals, much longer than values which produce even slight evidence of acquisition of nictitating membrane CRs, a relatively simple tone-light compound promoted the acquisition of CRs to distal CSs. The initial acquisition of CRs to CS1 provided evidence for theories which assume that classical conditioning can be extended over a prolonged series of stimuli to produce CRs which mediate sequences of overt instrumental behaviors (see Gormezano and Kehoe, 1981, 1982; Rescorla, 1977). The ultimate decline in responding to CS1 may reflect the development of an inhibitory potential based on a discrimination between CS1 and CS2 similar to that postulated by Pavlov (1927, pp. 103-104) to account for the phenomenon of "inhibition of delay" seen with extended CS duration.

To identify the mechanisms which promote the acquisition of CRs to CS1 in a serial compound, our research has focused on three interstimulus relations in a serial compound: CS1-CS2, CS1-US, and CS2-US. A considera-

tion of the interstimulus relations reveals that there are five broad classes of mechanisms which could contribute in a cumulative fashion to CR acquisition to CS1. Moreover, each class of mechanism can be tied to a specific combination of the interstimulus relations. The possible mechanisms and their requisite interstimulus relations are as follows:

a. Direct Conditioning of CS1. Direct conditioning of CS1 requires only CS1-US interval. Kehoe *et al.* (1979, Experiments 2 and 3) found that, in comparisons between serial compounds and corresponding CS1-US controls, facilitation of CR acquisition to CS1 by the serial compound was observable at CS1-US intervals of 1600 msec and longer, CS1-US intervals which by themselves failed to produce high levels of responding. Conversely, shorter CS1-US intervals (e.g., 750 msec) were themselves able to produce sufficiently high levels of responding to CS1 to mask or prevent the contribution of any other process operating in the serial compound.

b. Stimulus generalization. Stimulus generalization requires only CS2-US pairings, plus sporadic test presentations of CS1 to observe generalized responses. In our research, the contribution of stimulus generalization has been deliberately minimized by the use of a CS1 and CS2 which are from different sensory modalities (e.g., tone and light). Where assessments have been made, some cross-modal generalization has been observed in the the mean level of responding reaches values between 15% and 25% CRs, which exceed initial baseline values of less than 5% responses (e.g., Kehoe *et al.*, 1979, Experiment 2).

c. General Transfer. General transfer is distinct from stimulus generalization and requires both CS1-US and CS2-US pairings. A general transfer mechanism can be conceptualized as a learning-to-learn process analogous to that found in discrimination learning, in which acquisition of an "easy" discrimination facilitates acquisition of a "hard" discrimination (e.g., Pavlov, 1927, pp. 121-122; Seraganian, 1979). Similarly, CR acquisition to CS2, with its short CS-US interval, could facilitate CR acquisition to CS1, with its longer, otherwise ineffective CS-US interval. In actual practice, the use of intermixed CS1-US and CS2-US pairings provides a joint estimate of direct conditioning of CS1, stimulus generalization, and any general transfer from CS2 to CS1. With such "uncoupled" CS1-US and CS2-US training, the levels of responding to CS1 have reached only 20-40% CRs, which fall below the levels of 60-80% CRs to CS1 obtained in comparable serial compounds (Gibbs, 1979; Gormezano and Kehoe, 1982, Experiment 6; Kehoe *et al.*, 1979, Experiment 3).

d. Associative Transfer. Associative transfer relies on the CS1-CS2 and CS2-US pairings in a serial compound. Hypotheses about associative transfer are based on the phenomena of second-order conditioning (Frey *et al.*, 1971; Rescorla, 1973, p. 145; 1977) and sensory preconditioning

(Wickens, 1959, 1965, 1973), both of which involve procedurally separate CS1-CS2 and CS2-US pairings. Recently, it has been possible to obtain direct demonstrations of associative transfer by conducting training with separate but intermixed CS1-CS2 and CS2-US trials (Gormezano and Kehoe, 1981, 1982). Most notably, CR acquisition to CS1 was an inverse function of the CS1-CS2 interval, which parallels the "contiguity gradient" obtained with CS-US interval manipulations in the rabbit NMR preparation. Specifically, two investigations of the CS1-CS2 interval were carried out by Gibbs *et al.* (1979) and Kehoe *et al.* (1981b). Each day of training consisted of 30 CS1-CS2 trials interspersed with 30 CS2-US trials (CS2-US interval = 400 msec). In Gibbs *et al.*, separate groups received training at CS1-CS2 intervals of 400, 1400, 2400, 4400, and 8400 msec, whereas Kehoe *et al.* used CS1-CS2 intervals of 400, 800, and 2400 msec. To control for cross-modal generalization from CS2 to CS1 and any nonassociative contributions from the US, both studies contained an unpaired group, which received 30 unpaired presentations of CS1 and CS2 interspersed among 30 CS2-US pairings. Figure 15 shows the mean percentage CRs to CS1 as a

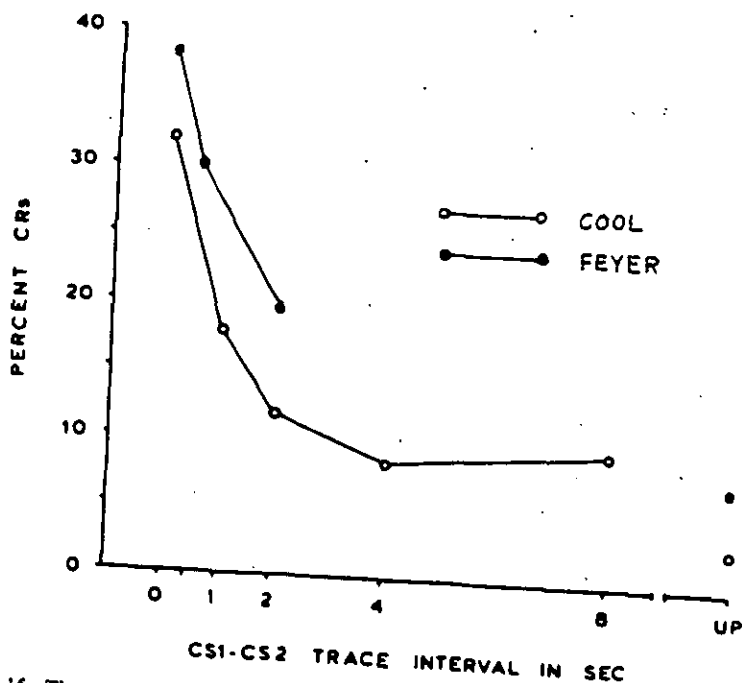


FIG. 15. The mean percentage of CRs to CS1 on CS1-CS2 paired trials plotted as a function of the CS1-CS2 trace interval. The function collected by Cool is extracted from Gibbs *et al.*, (1979), and the function collected by Feyer is extracted from Kehoe *et al.*, (1981).

function of the CS1-CS2 interval, which is designated by the "trace interval" between the offset of CS1 (400-msec duration) and the onset of CS2. Inspection of Fig. 15 reveals that responding to CS1 was highest at the zero trace interval (400-msec CS1-CS2 interval) and rapidly declined as the CS1-CS2 trace interval increased up to 2 sec. However, even for intervals of 2 sec and longer, Gibbs *et al.* found that the level of responding to CS1 was relatively stable at a point higher than that of the unpaired control.

The relatively steep gradient obtained with manipulation of the CS1-CS2 interval does not match the high level of performance obtained across CS1-CS2 intervals in reinforced serial compounds, in which initial CR acquisition to CS1 was uniformly rapid over a wide range of CS1-CS2 intervals. Although inspection of Fig. 15 indicates that there was some associative transfer to CS1 even at the longest CS1-CS2 intervals, the absolute level of responding to CS1 was low and did not approach the maximum levels of responding to CS1 in serial compounds with comparable CS1-CS2 intervals (cf. Kehoe *et al.*, 1979).

e. Serial Stimulus Mediation. Serial stimulus mediation relies on the integrity of the entire CS1-CS2-US sequence which composes a reinforced serial compound. Such a process would not entail associative transfer from CS2 to CS1. Instead, CS2 may be thought to bridge the long CS1-US interval, effectively foreshortening it. However, at present, the hypothesis of serial stimulus mediation represents a logical possibility which can gain support only indirectly by the elimination of other possibilities.

Our experimental separation of the interstimulus event pairs in serial compound conditioning has revealed that (a) the processes of direct conditioning, stimulus generalization, and general transfer, as estimated jointly by the use of uncoupled CS1-US and CS2-US training, can account for a portion of the CR acquisition to CS1 in a serial compound, and (b) associative transfer, as estimated by the use of intermixed CS1-CS2 and CS2-US trials, can produce reliable CR acquisition to CS1, but the absolute levels at the longer CS1-CS2 intervals would appear lower than required to account for the high levels of responding to CS1 in serial compounds at comparable CS1-CS2 intervals. Consequently, we are examining three plausible alternative hypotheses regarding the sources of responding to CS1 in a serial compound: (a) the estimates of associative transfer are too low, perhaps due to inhibitory factors arising from the unreinforced CS1-CS2 presentations (cf. Herendeen and Anderson, 1968; Holland and Rescorla, 1975); (b) a process of serial stimulus mediation operates in a reinforced serial compound (cf. Gormezano and Kehoe, 1982); or (c) the possible contributors combine in a synergistic rather than an independent fashion, i.e., the percentage CR measure is not linearly related to associative strength (Overmier, 1980; cf. Kehoe and Gormezano, 1980).

IV. Selected Topics

A. PARTIAL REINFORCEMENT

In both instrumental and classical conditioning, partial reinforcement procedures and their effects have a long history of research and sophisticated theory. In brief, a partial reinforcement procedure is one in which only a portion of the responses or CSs are followed by the reinforcer or US, respectively. Thus, partial reinforcement procedures fill the broad range of possibilities between extinction, in which presentation of the reinforcer is entirely suspended, and continual reinforcement, in which the reinforcer is presented following every response or CS. Moreover, from a global perspective, partial reinforcement has been regarded as one means for modeling the presumed unreliability and the intermittent nature of event sequences in the natural environment.

Across a wide variety of instrumental conditioning paradigms, partial reinforcement as compared to continual reinforcement produces (a) slower initial acquisition, (b) asymptotic levels that are as high (or higher), and (c) more prolonged responding during subsequent extinction, i.e., a partial reinforcement extinction effect (PREE). However, the results of partial reinforcement with classical conditioning paradigms have been less consistent: In human eye blink conditioning, partial reinforcement has a relatively permanent detrimental effect on both the rate and the asymptotic level of CR acquisition (e.g., Froseth and Grant, 1961; Ross, 1959; Schurr and Runquist, 1973; Spence and Trapold, 1961) but does produce a PREE (Grant and Schipper, 1952; Hartman and Grant, 1960; Perry and Moore, 1965). On the other hand, investigations of rabbit eye blink (Thomas and Wagner, 1964) and NMR (Gormezano and Coleman, 1975) conditioning have failed to reveal either a difference in the asymptotes or extinction performance under partial and continual reinforcement conditions. Failures to obtain a PREE have also been noted in other classical conditioning preparations (e.g., Gonzalez *et al.*, 1961, 1962; Longo *et al.*, 1962; Vardis and Fitzgerald, 1969).

In terms of understanding basic associative processes, the PREE has presented a paradox. A fundamental assumption of virtually all learning theories has been that each instance of reinforcement produces an increment in associative strength, even if a law of diminishing returns is true. If extinction performance is taken as a measure of overall associative strength, then the level of responding should be a direct function of the number of prior reinforcements. In support of these assumptions, early investigations with instrumental bar press procedures (Perin, 1942) manipulated the number of consecutive reinforced responses prior to extinction, where all responses

were reinforced, and found that the number of responses in extinction was directly related to the number of reinforced responses in acquisition. Accordingly, for a given number of trials during acquisition training, reinforcer presentation in all of them would be expected to produce the fastest acquisition and the highest level of performance during extinction. Although partial reinforcement does slow the rate of acquisition, its augmentation of responding in extinction is contrary to the expectations of the early theories. Accordingly, the determination of the effects of partial reinforcement on extinction of the conditioned NMR has implications regarding whether the NMR preparation should be viewed as a model for the associative processes postulated by the early learning theories or, alternatively, whether the NMR preparation is sensitive to the additional processes which have been postulated to account for the PREE (e.g., Capaldi, 1966).

In light of the systematic importance of partial reinforcement phenomena, a number of investigations using partial reinforcement have been conducted with the rabbit NMR preparation to determine its correspondence to other classical and instrumental preparations (Gibbs *et al.*, 1978; Gormezano and Coleman, 1975; Latham, 1971). In brief, partial reinforcement schedules have been found to have a deleterious effect on the rate of CR acquisition, but only schedules in which 25% or less of the CS presentations are paired with the US produce deficits in the asymptotic level of responding (Latham, 1971). Furthermore, if the training is started under a 100% reinforcement schedule and then reduced to a lower frequency of reinforcement, it is possible to reduce the frequency of reinforcement to 5% before any deficits in the likelihood of responding appear (Gibbs *et al.*, 1978). However, some deficits in CR amplitude do appear with schedules of less than 50% (Gibbs, 1976). Moreover, a PREE has been obtained when the schedule of reinforcement is shifted from 100% to 50% or 25% prior to extinction (Gibbs, 1976; Gibbs *et al.*, 1978, Experiment 1).

In acquisition, the CS-alone trials are not neutral but have a general decremental effect. Specifically, comparisons between continual and partial reinforcement conditions after an equal number of CS-US trials reveal that responding in the continual reinforcement condition is higher than in the partial reinforcement condition (Gormezano and Coleman, 1975). However, every, any local extinctive effects of CS-alone trials have proved difficult to detect; examination of the CR likelihood after sequences of one, two, and three nonreinforced trials have failed to reveal a reduction as compared to CR likelihood after a reinforced trial (Gibbs *et al.*, 1978; Gormezano and Coleman, 1975).

The accounts of the PREE most applicable to the NMR preparation are those in the tradition of Sheffield's (1949) "stimulus aftereffects" hypothesis and Capaldi's (1966) "sequential" theory. These accounts con-

tend that the effective CS consists of a compound of the nominal CS and hypothetical stimulus elements from the previous trial. Presumably, the US-UR occurrence on reinforced trials (R) gives rise to stimulus elements distinct from those arising from nonreinforced trials (N), which consist solely of CS-alone presentations. Consequently, animals trained under a continual reinforcement procedure have acquired CRs to the compound CS + R. Thus, when exposed to extinction, the level of responding would undergo a generalization decrement attributable to the change in stimulus conditions produced by the elimination of US presentations and, accordingly, US aftereffects (R). By the same token, animals trained under partial reinforcement would acquire CRs to two compounds: (a) CS + R and, more importantly, (b) CS + N. Consequently, in extinction after partial reinforcement, responding would undergo less of a decrement, since the prevailing stimulus conditions arising from the successive CS-alone presentations would resemble the compound CS + N.

Although a stimulus aftereffects/sequential account of the PREE in the NMR preparation appears plausible, it has been difficult to obtain converging evidence for the distinctive stimuli arising from reinforced and nonreinforced trials in the NMR preparation. In instrumental conditioning research, one important line of evidence has been the demonstration of "single-alteration" behavior which occurs when reinforced and nonreinforced trials are presented in a strictly alternating fashion. If the stimulus aftereffects of each trial are salient stimuli on the following trials, the aftereffects N and R would serve as CS+ and CS-, respectively. Thus, on reinforced trials, a response to N would be strengthened, whereas on nonreinforced trials, a response to R would never be strengthened. To date, the only instance of single-alteration behavior in the NMR preparation has been obtained by Hoehler and Leonard (1973). Their work required special conditions of high US intensities, a short (10-sec) intertrial interval after reinforced trials, and a longer (60-sec) intertrial interval after nonreinforced trials, conditions quite unlike those in which the PREE has been obtained. Although single-alteration behavior is difficult to demonstrate in the NMR preparation, this does not indicate a general insensitivity by the rabbit to the stimulus consequences of previous trials, for reliable single-alteration behavior has been obtained in the JMR preparation using a water US (Poulos *et al.*, 1971).

B. EXTINCTION AND INHIBITION

The associationistic tradition has tended to focus interest on the effects of CS-US pairings on observable CR acquisition. However, conditioning phenomena themselves are not confined to changes in behavior arising from the contiguity of two stimulus events. In fact, Pavlov devoted a considerable

portion of his research effort to inhibitory phenomena, which are characterized by the suppression of responding arising, in part, from the presentation of a CS by itself. More recently, inhibitory phenomena have again attracted considerable interest as revealing processes which serve to govern the potentially runaway, excitatory effects of CS-US pairings (cf. Rescorla, 1967, 1969, 1975; Boakes and Halliday, 1972).

The most familiar inhibitory phenomenon is extinction. The operations of extinction entail the presentation of the CS by itself after prior CR acquisition training with CS-US pairings. The behavioral extinctive outcome entails the decline in the frequency and/or amplitude of CRs over successive CS presentations. Quite frequently, the extinction procedure is used essentially as a lengthy series of test trials for assessing the excitatory associative consequences of prior CS-US pairings. Furthermore, it is tempting to attribute behavioral extinction to unlearning of the association formed during acquisition training. Although the extinction procedure is an undeniably useful test procedure, there are substantial data to indicate that extinction has interesting characteristics of its own and cannot be simply construed as an unlearning process.

In the rabbit NMR and JMR preparations, extinction is characterized by declines in CR frequency within a session, but between extinction sessions there is frequently a pronounced increase in the level of responding (i.e., "spontaneous recovery"). Although both the NMR and JMR preparations display systematic extinction, the process is quite prolonged, contrary to the prevailing mystique that CRs are generally labile and readily eliminated by extinction (cf. Kimble, 1961). A variety of both associative and performance accounts have been used to explain extinction (Estes, 1955; Hull, 1943), but in any case, the empirical phenomenon of spontaneous recovery indicates that a substantial fraction of the extinctive decrement does not reflect a corresponding unlearning. A more telling blow to an unlearning hypothesis of extinction is the results of successive acquisition and extinction procedures. According to the unlearning hypothesis, the associative connection should be broken by extinction and the animal should be effectively returned to the naive state with respect to the particular association. However, CS-US pairings after extinction produce faster CR acquisition than the original CS-US pairings. Moreover, alternation of acquisition and extinction sessions produces progressively faster increases and decreases in CR frequency (Smith and Gormezano, 1965). At a minimum, both acquisition and extinction are equally subject to substantial savings.

A more well-developed area of research and theory is connected with the phenomenon of conditioned inhibition (Marchant *et al.*, 1972; Marchant and Moore, 1974). The essential feature of Pavlov's conditioned inhibition paradigm entailed reinforced presentations of one CS (CSA-US) which were

interspersed with unreinforced presentations of CSA compounded with another CS (CSA + CSX). With sufficient training, the animal comes to respond to CSA but not to the compound stimulus. Presumably, the loss in responding to the compound represents the algebraic sum of the demonstrated excitatory capacity of CSA and a hypothetical negative inhibitory capacity acquired to CSX. As defining operations for the inhibitory capacity of CSX, Pavlov (1927) and, more recently, Rescorla (1969) and Hearst (1972) have provided detailed criteria for demonstrating the capacity of a suspected inhibitor to suppress responding. Thus, following conditioned inhibition training, the compounding of CSX with a CR-evoking stimulus (CSB) should lower the likelihood of a CR relative to CSX alone. Rescorla (1969) points out that a successful "summation test," although necessary, is not sufficient for establishing the inhibitory capacity of CSX. In addition, it is essential to rule out the possibility that the suppressive effect of CSX in combination with CSB is not merely a decremental consequence related to the novelty of the test compound. As a necessary converging operation for demonstrating the inhibitory capacity of a stimulus, Rescorla proposed a "retardation test" consisting of reinforced acquisition training in which CSX is paired with the US. According to Rescorla, a CSX which is sufficiently salient to have decremental effects on CSB's CR-evoking capability, thereby producing a suppression of responding to the novel compound, should acquire excitatory properties quite rapidly. On the other hand, if CSX does possess an inhibitory capacity, overt CR acquisition should be retarded in that the negative inhibitory capacity needs to be overcome.

Moore and his associates have performed a series of experiments with the NMR preparation which have successfully demonstrated the acquisition of inhibitory properties to a CS under the most stringent criteria. The initial experiment, conducted by Marchant *et al.* (1972), obtained both suppressive summation and retardation during final CSX-US training. Subsequently, Marchant and Moore (1974) used CSX-US acquisition training to show that retardation of acquisition to CSX was a specific result of prior training in which an unreinforced compound of CSA + CSX was contrasted to reinforced CSA-US training. When the unreinforced compound (CSA + CSX) was contrasted to reinforced training of a third stimulus (CSB-US), subsequent CSX-US training showed some positive transfer relative to control groups which had not received any prior training.

The findings of Marchant and Moore (1974) were consistent with arguments that inhibition accrues to a stimulus as a consequence of nonreinforcement in the immediate presence of excitation (Pavlov, 1927; Wagner and Rescorla, 1972). Conditioned inhibition training satisfied this stipulation since nonreinforcement of CSX occurs in the presence of the excitatory

CSA. However, in Marchant and Moore's (1974) latter group, CSA, itself having never been paired with the US, could not provide the necessary excitatory component for the development of inhibition during nonreinforced AX compound presentations (Marchant and Moore, 1974).

A recently discovered phenomenon, "latent inhibition," indicates that at least some inhibitory effects can be obtained without prior excitatory conditioning. In brief, latent inhibition is said to occur when exposure to the CS alone prior to CS-US pairings hinders subsequent CR acquisition (Lubow, 1973). Thus, the defining operations for latent inhibition are those of the "retardation" test of conditioned inhibition. Latent inhibition has been demonstrated in the NMR preparation (Clarke and Hupka, 1974; Solomon *et al.*, 1974a; Solomon and Moore, 1975), with the degree of retardation appearing to be an increasing function of the number of prior CS exposures (Clarke and Hupka, 1974). After 500 CS presentations, Clarke and Hupka (1974, Experiment 2) found that the mean level of CR acquisition over the initial 3 days of CS-US acquisition training (100 trials/day) fell 40 percentage points below that of a control group which had not received prior CS presentations. However, the inhibitory effect was not permanent, since the CR level in the preexposed group rose to an asymptote equal to that of the unexposed control group.

Although CS exposures produce retardation of CR acquisition, summation testing has not indicated that CS exposure is sufficient to suppress responding to an already established CS (Solomon *et al.*, 1974a; Solomon *et al.*, 1974b; Solomon and Moore, 1975). Consequently, the latent inhibition procedure does not produce a CS with the same characteristics as the conditioned inhibition procedure. Since latent inhibition does not meet the conventional criteria for an "active inhibitor," investigators of latent inhibition have interpreted it as resulting from a "loss of cue salience by way of an habituation-like process" (Solomon *et al.*, 1974; cf. Moore, 1979, Moore and Stickney, 1980). However, the exact parallels between latent inhibition and conventional habituation phenomena remain to be specified.

Even though the key feature of inhibitory operations is the presentation of CSs by themselves rather than in contiguity with a US, a large number of hypotheses have attempted to place inhibitory phenomena in an associationistic framework. Among these hypotheses, S-R formulations contend that the decrement in responding during CS-alone presentations represents the replacement of the observable CS-US association with a new excitatory association between the CS and a hypothetical response which is incompatible with the CR (Guthrie, 1930, 1959; Hull, 1943; Weinstock, 1970; Wilson and Davison, 1971). In contrast, the most naive form of S-S theory attributes the active characteristics of an inhibitor to an association between the CS and the absence of the US. This postulation of a CS-US associa-

tion entails treating a nonevent as if it were the functional complement as well as the logical complement to the event in question. However, more advanced S-S theories have avoided postulating a functional nonevent by resurrecting Pavlov's (1927) contention that acquisition of inhibitory potential arises from a contrast between an unreinforced CS presentation and concurrent excitatory associative strength (cf. Rescorla and Wagner, 1972; Wagner and Rescorla, 1972). Thus, in the conditioned inhibition paradigm, the potential of CSX is driven into the negative range when it occurs in conjunction with the unreinforced presentation of the excitatory CSA (cf. Gormezano and Kehoe, 1981).

C. NMR-JMR INTERACTIONS

Recently, transfer between the NMR and JMR systems has been used to examine "dual-motivational" theories, which are a variety of CR-mediational theory. Most notably, dual-motivational theories assume that, during classical as well as instrumental conditioning, covert CRs (e.g., "drive" CRs) are acquired to the stimuli antedating the reinforcer. These covert CRs have motivational consequences for the overt behavior corresponding to the appetitive or aversive nature of the reinforcer. Moreover, dual-motivational theories assume that appetitive and aversive motivational states influence each other in an antagonistic fashion (Dickinson and Pearce, 1977; Gray, 1975; Konorski, 1967; Miller, 1963; Mowrer, 1960; Rescorla and Solomon, 1967). Hence, the final valence and intensity of motivation for overt behavior are assumed to be determined by the algebraic summation of opposing appetitive and aversive sources.

Dual-motivational theories were originated to account for "approach-avoidance conflicts" and were tested with instrumental runway procedures in which the goal box contained both food and shock (Brown, 1948; Miller, 1944). Subsequently, dual-motivational theories have guided extensive research using classical-instrumental transfer (CS-IR) paradigms, e.g., conditioned suppression, in which a CS paired with, say, an aversive US is presented during instrumental behavior based on an appetitive reinforcer (Estes and Skinner, 1941; Hunt and Brady, 1951; Kamin, 1965). Early formulations and tests of dual-motivational theory focused on the effects of motivational states on instrumental behavior in which the acquisition of motivational states was anchored to the empirical (or presumed) laws of overt classical conditioning (CS-CR). However, more recent formulations have contended that "central" and unobservable motivational CRs influence overt CRs as well as instrumental behavior (Dickenson and Pearce, 1977; Konorski, 1967; Rescorla and Solomon, 1967). In addition, Konorski (1967), for example, has argued that the acquisition of hypothetical central

CRs follows different quantitative laws than the acquisition of overt CRs, thus loosening empirical constraints on the acquisition of the hypothetical mediating CRs.

Whereas the original dual-motivational theories implied that CRs based on appetitive and aversive USs are independently acquired to the same CS, the more recent formulations expect interference if the same CS is paired with two USs with different motivational consequences. Accordingly, to determine whether interference occurs between acquired motivational systems, transfer from NMR conditioning based on a presumptively aversive shock US to JMR conditioning based on a presumptively appetitive water US has been examined by Scavio (1974), Bromage and Scavio (1978), and Scavio and Gormezano (1980). In the first experiments by Scavio (1974), separate groups of rabbits were given tone-shock pairings, unpairings, or exposure to the apparatus (sit-control). During the initial stage, only animals in the paired condition showed NMR conditioning. Throughout training, all groups received a restricted water ration of 90 ml of water per day. In the second stage, all groups received transfer testing with tone-water pairings suitable for JMR conditioning. Relative to unpaired and sit-control conditions, prior tone-shock pairings retarded the acquisition of jaw movement CRs. During the second stage of tone-water pairings, NMRs to the tone CS declined faster than in a CS-alone extinction procedure (Scavio, 1974, Experiment 2). Subsequently, Bromage and Scavio (1978) duplicated the negative transfer effects of tone-shock pairings to subsequent JMR conditioning under a more severe 60-ml/day deprivation regimen, but not under a less severe 120-ml/day regimen. Although Scavio (1974, Experiment 2) found that a previously acquired NMRL was depressed by tone-water pairings, Scavio and Gormezano (1980) did not find that there was always negative transfer from JMR conditioning to NMR conditioning. In fact, they found that prior tone-water pairings facilitated NMR acquisition during subsequent tone-shock pairings. These findings, indicating an asymmetry between negative aversive-appetitive transfer and positive interactions, although not the simplistic variants which postulate a uniform mutual antagonism (cf. Dickinson and Pearce, 1977).

The use of transfer designs to infer properties of alleged central conditioned motivational states has the potential risk of being confounded by the presence of peripheral response interactions. Specifically, CS-IR procedures, which presumably measure the effects of the central motivational CRs, may have been subject to interactions between peripheral instrumental responses as well as classically conditioned responses (Dickinson and Pearce, 1977; Gormezano and Kehoe, 1975; Overmier and Lawry, 1979; Trapold and Overmier, 1972). Thus, a positive or negative transfer effect may occur

simply because mutually facilitory or antagonistic behaviors are elicited by the CS and/or reinforcers. On the other hand, in the studies of Bromage and Scavio (1978) and Scavio (1974), the joint occurrence of nictitating membrane and jaw movement CRs during transfer testing were found to be statistically independent events. The statistical independence of these two response systems strongly suggests that they did not mechanically conflict with one another to yield the interaction effects.

D. PHARMACOLOGICAL STUDIES

The earliest research regarding the behavioral effects of pharmacological agents was conducted by Pavlov (1927, p. 35), who examined acquisition of the overt responses produced by apomorphine to the cues arising from the antecedent injection procedure. Despite Pavlov's pioneering efforts, drug research with the CS-CR procedure has been rare compared to the numerous experiments using instrumental procedures. However, because of the experimenter's control over presentation of the CS and US and its well-developed control methodology, classical conditioning appears to have a great deal to offer for detailing the behavioral effects of drug interventions. Accordingly, we have recently begun to use the NMR preparation to delineate the mode of action of purportedly psychotropic drugs.

1. Theoretical Models of Drug Action

a. Three-Component Model. To implement a program of psychopharmacological assessment, it was necessary to adopt an interim model of the conditioning process. From our earlier discussion, it should be apparent that the current body of conditioning theory consists of a multitude of contending formulations, e.g., contiguity vs. effect vs. contingency. The didactic assertion of any one formulation would undoubtedly yield a distorted methodology for assessing drug effects. Consequently, we adopted a more general framework which could easily be put to use and could accommodate a wide variety of formulations. Specifically, we attempted to distinguish between drug effects on three hypothetical components which intervene between the observable sensory input and the behavioral output: (a) sensory processing of stimuli; (b) learning processes; and (c) motor functioning. Each of these processes can be readily subdivided to suit a specific formulation. For example, the sensory processing component can be construed as including everything from the functioning of sensory detectors up to more molar "trace," "attentional," or "short-term memory" processes. Similarly, the so-called associative process can be subdivided to include relatively distinct associative and incentive processes. In any event, the learning process is presumed to entail the long-term alterations produced by experiences

which are connoted by the term "learning." Finally, motor functioning can include not only specific effector functioning but also nonspecific energizing factors.

b. A Note on the Learning-Performance Hypothesis. One three-component framework is orthogonal to the long-standing but deceptive distinction between "learning" and "performance." On the one hand, the learning-performance distinction has been useful as an acknowledgment that behavior at any given moment is determined in a multiple fashion by current, relatively temporary organismic states which may mask or reveal the more permanent latent consequences of past experience. On the other hand, the learning-performance distinction has fostered the illusion that it is easy to ascertain the relatively irreversible and reversible effects of any given variable. In fact, not all behavior theories acknowledge a learning-performance distinction (cf. Brown, 1961, pp. 99; Guthrie, 1959), and those which do (e.g., Hull, 1943, 1952) also recognize that many variables can enter both the learning process, either by producing associable stimuli or through an effect process, and the performance process by altering current stimulating or motivational conditions. A case in point is the variable of CS intensity. In Hull's (1943, 1952) theory, CS intensity is a performance variable in that it has a dynamogenic effect on current behavior. However, the particular intensity of a CS is also an associative variable in that (a) CS intensity determines, in part, the increment in associative strength on each reinforced trial, and (b) the particular value of a CS used during training is a conditionable stimulus dimension and, thus, responding is subject to a generalization decrement if another value is presented. Similarly, it is possible that a given drug could have multiple temporary and permanent effects which interact with each other. It is hoped that by first delineating the component(s) processes affected by a drug, the later determination of the relatively temporary or permanent nature of the drug effects will be easier to make.

2. A Set of Converging Operations

Our current battery of procedures for assessing drug effects was developed in connection with the investigation of LSD. In brief, the strategy has been one of progressive refinement in the localization of the drug's effect.

a. Dose-Response Curve. The initial assessment of the drug's action took the form of a dose-response curve. Gimpl *et al.* (1979) trained separate groups of rabbits under doses of 0 (saline, vehicle), 1, 10, 30, 100, and 300 nmol/kg IV. Different groups received 30 tone-shock pairings intermixed with 30 light-shock trials per day for 10 days. The CS-US interval was 800 msec. The study revealed a biphasic dose-response curve in which dosages of

1-100 nmol/kg significantly enhanced CR acquisition, with the maximal enhancement occurring at 30 nmol. However, the 300-nmol/kg dose retarded initial CR acquisition relative to the vehicle control.

b. Unpaired Stimulus Presentations. In assessing the dose-response curve in paired training, a parallel set of unpaired control groups received 30 tone, 30 light, and 60 shock trials per day presented in an intermixed fashion. In the unpaired groups, the level of responding to either the tone or light CS was negligible (2-4%) across all dosage levels. Thus, the enhancing effect of LSD on CR acquisition could not be attributed to such nonassociative factors as an elevation in the base rate of responding, sensitization, or pseudoconditioning. Furthermore, since no differences were apparent between responding to the tone vs. light CS in either the paired or unpaired groups, LSD's effects were not confined to input from a particular sensory modality. Although the paired vs. unpaired comparison indicated that LSD's effects acted through the contiguity component of the learning process, further assessment was required to determine whether the action of LSD would be characterized as altering the sensory processing of the stimuli, altering the effectiveness of the presumed associative connection as such, and/or facilitating motor output.

c. US-UR Assessment. The effects of LSD on the US-UR relationship have been determined by examining the amplitude of the UR to the 3-mA shock US under the various doses (Gimpl *et al.*, 1979; Experiment 1) and by examining the amplitude and frequency of URs across US amplitudes ranging from 0.0625 to 4.0 mA (Gormezano and Harvey, 1980, Experiment 2). In the case of LSD, the drug in a dose of 30 nmol failed to alter UR amplitude or to lower the threshold for UR evocation as compared to vehicle controls. In terms of the three-component model, the examination of the US-UR function suggests that LSD did not affect sensory processing of the US or motor functioning of the UR.

d. CS Manipulations. An assessment of the effects of LSD on the sensory processing of the CS in relative isolation from the learning process was made by examining CR likelihood when CS intensity is varied after CR acquisition has occurred (Gormezano and Harvey, 1980, Experiment 3). Post acquisition manipulation of the CS intensity revealed that the 30-nmol dose raised the likelihood of a CR by approximately 10 percentage points across the range of CS intensities, thus indicating lowering of the sensory threshold for evoking a CR to a tone CS. A preacquisition assessment of CS processing has been developed by using ISI-UR amplitude functions (cf. Hoffman and Ison; Ison and Leonard, 1971; Thompson, 1976), which measure the inherent capacity of the CS to modulate the UR to a weak US (Harvey and Gormezano, 1981). If LSD facilitates CS processing, then LSD should pro-

duce augmentations in UR amplitude over control levels at all but perhaps the shortest and longest CS-US intervals. Since LSD administration but augmented CR acquisition and CS intensity effects on CR performance but not on measures of the US-UR, Gormezano and Harvey (1980) concluded that LSD has effects functionally equivalent to increasing the physical intensity, or salience, of the CS. In more theoretical terms, LSD may be said to have a dynamogenic effect which (a) augments the increment in associative strength on each CS-US trial and (b) potentiates current responding. Thus, an alteration in the sensory processing of the CS ramifies into the associative process. Recently, Harvey and Gormezano (1981) have applied the same battery of procedures, plus the ISI-UR amplitude procedure, to an assessment of haliperidol and found converging evidence that it depresses CS processing. Consequently, our procedures are sensitive to both incremental and decremental effects of drugs.

e. Future Assessment. The findings with LSD and haliperidol suggest that these drugs change the effective intensity (salience) of the CS, but additional questions may be raised regarding the nature of the apparent alterations in CS processing. First, do drugs alter the time course of CS processing, i.e., the form of the CS trace? The temporal properties of CS functioning can be assessed by locating CR peaks under drugs. For example, if LSD produces an increase in the speed of CS processing, then administration of LSD after CR acquisition would be expected to produce more rapid CR recruitment and a shift in the peak of the CR to a time in advance of its usual location coinciding with the time of US occurrence (cf. Smith, 1968). Second, does an alteration in CS salience lead only to an increase or decrease in the dynamogenic effects of the CS? Or does the alteration in CS salience affect the discriminability and/or attentional value of the CS? These alternatives can be operationalized by examining differential conditioning, conditional discriminations, and/or conditioned inhibition under drugs. If, for example, LSD enhances the dynamogenic effect of the CS, conditional discriminations or conditioned inhibition, which require a suppression of overt responding, may be difficult to produce. However, if LSD refines the processing of the CS, then conditioned inhibition might be easier to establish. Similar questions can be couched in terms of signal detection theory and tested in discrimination paradigms (cf. Suboski, 1967). Specifically, if LSD shifts the animal's bias toward responding, then there would be parallel increases in the level of responding to CS+ and CS- in a differential conditioning paradigm. If LSD increases the discriminability of two different CSs, then there would be increased responding to CS+ and decreased responding to CS-. As can be seen, the systematic employment of known conditioning phenomena provides substantial power for the systematic elucidation of the modes of drug-induced alterations in acquired behavior.

V. Conclusion

Hopefully, we have persuaded the reader that classical conditioning, in general, and the NMR preparation, in particular, are powerful tools for the investigation of a wide range of biological and psychological questions. In particular, Pavlov's intention of using classical conditioning to study the neural pathways and processes of behavioral adaptation appears to be occurring. Frankly, it has been gratifying to see neurobehavioral investigators (e.g., Thompson, 1976) adopting the rabbit NMR preparation on the basis of its well-documented and robust parametric effects. For similar reasons, the use of the NMR preparation in psychopharmacology appears to be promising. However, the original motive for developing the rabbit preparation was the need for classical conditioning data of a quality suitable for studying associative learning processes and substantiating the associative axioms of more extensive behavior theories. By the systematic study of major parameters, especially the CS-US ISI, and the detailing of CR topography, it has been possible to reveal the empirical counterparts and anomalies of the historical Law of Contiguity. Guided by CS trace theory, these data have made possible the precise measurement of the emergence and acquisition of the anticipatory CR. In the future, we hope to manipulate the moment-to-moment characteristics of the CS (e.g., frequency and amplitude) and thereby further delineate the determinants of CR timing. With the existing body of data, it has been possible to move forward on a systematic examination of CR acquisition to compounds of tone and light CSs. In these investigations, we have been able to discover processes of associative transfer which extend the temporal bounds of conditioning beyond the empirical CS-US contiguity gradient; stimulus selection which appears to attenuate CR acquisition within the bounds of empirical CS-US contiguity; and conditional discrimination which indicate the effective combination of temporally separate CSs. Thus, even the most minimal increase in the complexity of the stimulus environment has revealed that classical conditioning with the rabbit NMR preparation can be used as a behavioral test tube for revealing the laws governing the interactions and integration of the stream of stimulus events to which an organism must adapt. It appears that we have yet to reach the limits of what can be learned from rabbit preparations about conditioning and brain functioning.

Acknowledgments

The preparation of the manuscript and the research reported were supported primarily by grants from the National Science Foundation to I. Gormezano, as well as NIDA grant DA01759 (I. Gormezano, Co-PI), grants for the Australian Research Grant Committee and the University

of New South Wales Special Studies Project to E. J. Kehoe, and NIMH Grant MN15773 to B. S. Marshall. The critical reading of the manuscript by B. G. Schreurs is gratefully acknowledged.

The development of the rabbit conditioning preparations and the behavioral research reported was supported by grants from the National Science Foundation. The research on drug effects has been supported by NIDA. Grants from the Australian Research Grant Committee and University of New South Wales Special Studies Project to E. J. Kehoe, and NIMH Grant MH 15773 to B. S. Marshall supported their participation in the preparation of the manuscript. The critical reading of the manuscript by B. G. Schreurs is gratefully acknowledged.

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