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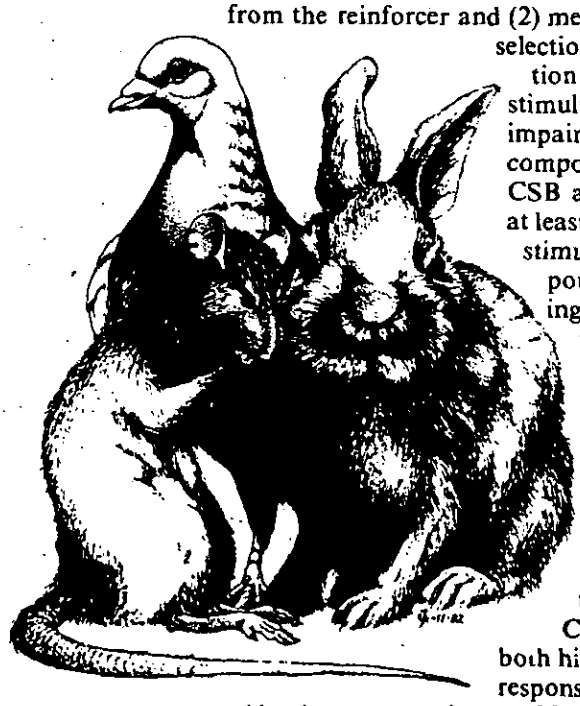
This article reviews the theory and research concerning the processes governing response acquisition to the components of a serial compound stimulus, e.g., CSA-CSB-US. Research with serial compound stimuli is pertinent to two theoretical issues: (1) the mechanisms which facilitate the acquisition of associative strength to stimuli which are temporally remote from the reinforcer and (2) mechanisms underlying "stimulus selection" effects in which an association between a relatively contiguous stimulus and reinforcer appears to be impaired by other components of a compound. Response acquisition to CSB appears to suffer impairments, at least when CSB is tested outside the stimulus context of the serial compound. However, there is emerging evidence that, inside the context of a serial compound, the CSB-US relation exerts a greater impact on response acquisition than the test results would suggest. With regards to CSA, the outcome appears to depend on the relative effectiveness of the CSA-US and CSB-US intervals. Where the CSA-US and CSB-US intervals are themselves both highly effective for conditioning, response acquisition to CSA is impaired by the more contiguous CSB. In some cases, there have been mutual impairments in response acquisition to CSA and CSB. Where the CSA-US interval is longer and promotes little or no conditioning, response acquisition to CSA has been highly facilitated by the presence of CSB in a serial compound. In connection with the issue of remote associations, the data suggest that processes of stimulus generalisation and second-order conditioning contribute to the facilitation of remote associations, but it is not clear whether they account for the



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CONDITIONING WITH SERIAL COMPOUND STIMULI: THEORETICAL AND EMPIRICAL ISSUES

Any organism, in even the most sterile environment, is faced with a continual stream of stimulus events in every sense modality. In order to discover the laws governing behavioural adjustments to an everchanging environment, Pavlov (1927, pp. 110-113) and subsequent investigators have used compounds of separable stimuli (e.g. tone + light) as a laboratory model for the array of innocuous events which regularly precedes a biologically significant stimulus (e.g., Hull, 1943; Kehoe & Gormezano, 1980; Razran, 1965, 1971; Wickens, 1954, 1959, 1965). More particularly, research with compounds of serially presented stimuli is playing a particularly important role toward resolving two key theoretical issues concerning behaviour in a complex environment.

The first theoretical issue concerns facilitation of remote associations. Although contiguity principles assert that successive events must occur closely together to be associated, routine observations in maze-learning and operant chaining clearly indicate that stimuli which have been temporally remote from a goal become capable of initiating long sequences of goal-directed behaviour (Bindra, 1978; Gollub, 1977; Kelleher, 1966; Lashley, 1951; Tolman, 1949). The various mechanisms which have been thought to bridge long temporal intervals have all been predicated on the assumption that there are regular sequences of stimulus events which provide a basis for either mediated associations or transfer based on stimulus generalisation among the members of the sequence (Grice, 1948; Hilgard & Marquis, 1940, pp. 210-221; Hull, 1930, 1931, 1934; Konorski, 1948, 1967; Logan & Wagner, 1965; Spence, 1956). Consequently, the investigation of conditioning with serial compounds should provide insights into mechanisms which effectively extend the range of contiguity based learning and enable the establishment of lengthy sequences of behaviour.

The second theoretical issue concerns "stimulus selection" effects. It has long been recognised that not every pair of contiguous events becomes equally well associated. Since the emergence of Brown's (1820, pp. 199-214) secondary laws of association, considerable efforts have been devoted to identifying processes such as "attention" and "perception" which constrain the formation of associations by contiguity (e.g., Gormezano & Kehoe, 1981; Kamin, 1968, 1969; Lashley, 1929, 1942; Riley & Leith, 1976; Rudy & Wagner, 1975, pp. 270-272; Wickens, 1954, 1959). Investigations with serial stimuli have provided particularly dramatic cases in which an association between a relatively contiguous stimulus and reinforcer appears to be impaired by a preceding stimulus which is less contiguous with the reinforcer (e.g., Egger & Miller, 1962; Wickens, 1959, 1965, 1973).

The following discussion is in three parts. The first part defines more precisely the scope of the present review in terms of the kinds of empirical methods and outcomes which will be considered. The second part deals with a theoretical analysis of processes in serial compound conditioning. Finally, the third part reviews empirical research with serial compounds focusing on the key stimulus relationships in those compounds.

PRELIMINARY CONSIDERATIONS

Interaction and Integration Laws

Any conditioning procedure with compound stimuli logically allows observation of both the interaction and integration of the component stimuli. An interaction may be said to occur whenever response acquisition to one stimulus in a compound is influenced by training in conjunction with other components. There are two types of interactions: the positive type, in which response acquisition to the target stimulus is facilitated by compound stimulus training, and the negative type, in which response

acquisition to a stimulus is impaired by training in a compound stimulus. Thus, studies of "facilitation" of remote associations deal with positive interactions, while studies of "stimulus selection" deal with negative interactions. While an interaction law describes the relation between the components of a compound, an integration law describes the relation between the compound and its components (Kehoe & Gormezano, 1980). The lawfulness of the relation between responding to the compound and its components is the central focus of research concerned with delineating combination rules for compound stimuli. However, historic controversies arising from Gestalt psychology (cf., Hull, 1943; Razran, 1939, 1965, 1971; Rescorla, 1972a, 1973a) have directed research toward determining whether or not a compound stimulus fuses into a "configuration," i.e., an event which is functionally distinct from its components (Baker, 1968; Bellingham & Gillette, 1981; Gillette & Bellingham, 1982; Kehoe & Gormezano, 1980; Razran, 1971). Moreover, evidence from studies of serial learning (Straub, Seidenburg, Bever & Terrace, 1979), memory for sequential stimuli (Weisman, Wasserman, Dodd & Larew, 1980) and discrimination between different serial compounds and their components (Ross & Holland, 1981; Kosiba & Logan, 1978; Marshall, Gray & Gormezano, 1980) indicate that animals are capable of integrating serial stimuli. Although the resolution of issues concerning integration will ultimately have profound implications for theories of stimulus interaction, it is still possible to deal with stimulus interactions in relative isolation. Assumptions regarding integration laws will, however, be noted where relevant.

Nomenclature

Although investigations of conditioning with serial compounds have been conducted with diverse procedures and species, they have typically used the simplest possible compounds: two distinctive conditioned stimuli (CSs) with different onset times followed by the reinforcer/unconditioned stimulus (US). Nomenclature has tended to vary with some investigators using the order of succession to enumerate the two stimuli, i.e., CS1-CS2-US, and others enumerating the stimuli according to their temporal proximity to the reinforcer, i.e., CS2-CS1-US. To avoid this confusion, the present review will uniformly refer to the stimulus with the earliest onset as CSA and the stimulus with the later onset as CSB. Thus, a reinforced serial compound will be designated CSA-CSB-US (cf. Kehoe, Feyer & Moses, 1981a; Pearce, Nicholas & Dickinson, 1981). This designation will be used in connection with both strictly sequential compounds, in which the offset of CSA precedes the onset of CSB, and overlapping compounds, in which CSA and CSB have a simultaneous offset (cf. Baker, 1968). However, enumerated CS designations (i.e., CS2 and CS1) will still be used in reference to explicit second-order conditioning procedures in which the compound trials (CS2-CS1) are separate from reinforced trials (CS1-US).

Many of the studies in the following review are concerned with the temporal relations between the stimuli of a compound. Once again, nomenclature has varied. To avoid confusion, 'CS-US intervals' and 'CS-CS intervals' will be defined in terms of the interval from the onset of the first stimulus to the onset of the second stimulus. Other aspects of the temporal relations between stimuli, e.g., the degree of overlap between stimuli, will be described as needed.

THEORY

Although a serial compound consisting of just two CSs might appear to involve only a slight increase in complexity over CS-US training, the number of hypotheses concerning interaction between two CSs is staggering. Moreover, many of the proposed processes are compatible with one another. It is conceivable that many of them could contribute in an algebraic fashion to the level of responding to each CS. While this state of affairs is theoretically inelegant, a large number of coexisting behavioural processes may truly reflect the underlying flexibility of the neural

processes governing behavioural adaptation. In order to identify the contribution of each process to response acquisition in a serial compound, research has focused on three interstimulus relations in a serial compound, viz., CSA-CSB, CSA-US, and CSB-US. Each of the various possible processes can be tied to a specific combination of the interstimulus relations. Furthermore, the possible processes can be subdivided according to whether they are expected to facilitate or impair responding to CSA and/or CSB.

CSA-US and CSB-US Relations

Direct Conditioning

Both CSA and CSB of a serial compound are subject to direct conditioning according to their individual relations with the US, e.g., CS-US intervals. Direct conditioning is not necessarily excitatory in nature, for long CS-US intervals can produce inhibitory conditioning (e.g., Hinson & Seigel, 1980). The level of direct conditioning for each CS can be independently assessed by using single-stimulus control groups, each of which is given CS-US training with either CSA or CSB. The level of responding obtained for each separately trained CS provides the baseline against which both positive and negative interactions are detected in compound conditioning procedures (Kehoe, 1979; Wickens, 1959, 1965).

Stimulus Generalisation

In addition to direct CS-US conditioning, the CS-US training for one CS can influence the level of responding to the other CS in the compound. Most notably, stimulus generalisation from CSB to CSA has been proposed to facilitate responding to CSA (Levis, 1966; Levis & Stampfl, 1972). The experimental assessment of stimulus generalisation requires only CSB-US pairings plus sporadic test presentations of CSA to observe generalised responses.

General Transfer

General transfer is distinct from stimulus generalisation. In particular, its experimental assessment requires both CSA-US and CSB-US pairings. A general transfer mechanism can be conceptualised 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 CSB with its short CS-US interval could facilitate CR acquisition to CSA with its longer, otherwise ineffective CS-US interval. In practice, the use of intermixed CSA-US and CSB-US pairings provides a joint estimate of the direct conditioning of each CS, stimulus generalisation between CSs and any general transfer from CSB to CSA.

Differential Inhibition

Differential inhibition also relies on the CSA-US and CSB-US pairings and, more particularly, on the disparity between their respective CS-US intervals (Brahlek, 1968; Frey, Englander & Roman, 1971; Rescorla, 1972b, p. 32; Sheffield, 1965, pp. 308-309; Williams, 1965, p. 341). Pavlov (1927, pp. 103-104) might be regarded as the earliest proponent of a differential inhibition hypothesis, which appeared in his explanation of "inhibition of delay". By progressively increasing a short CS-US interval to a longer CS-US interval of several minutes in length, Pavlov (1927, p. 89) found that the initiation of the CR came to occur late in the CS-US interval. Pavlov (1927) argued that a long CS could be regarded as a serial compound with the successive elements arising from the time-dependent processes initiated by the CS. Appealing to the empirical laws of differential conditioning, Pavlov argued that the

initial CS elements, through their distance from the US, became effectively a CS and accordingly acquired inhibitory properties.

The CSA-CSB Relation

The CSA-CSB relation has usually been thought to facilitate responding to CSA in a serial compound, specifically through processes of associative transfer. The experimental demonstration of associative transfer relies on the CSA-CSB and CSB-US pairings in a serial compound. Hypotheses about associative transfer are based on the phenomena of second-order conditioning (Frey et al., 1971; Rescorla, 1973b, p. 145) and sensory preconditioning (Wickens, 1959, 1965, 1973), both of which involve procedurally separate CSA-CSB and CSB-US pairings. However, the contrast between unreinforced CSA-CSB presentations and the CSB-US pairings also introduces the procedure for the acquisition of conditioned inhibitory properties to CSA (e.g., Herendeen & Anderson, 1968; Kehoe et al., 1981a). Thus, the usual procedures for demonstrating associative transfer may underestimate its contribution inside a reinforced CSA-CSB-US sequence.

The CSA-CSB-US Sequence

Although the experimental separation of a serial compound into its constituent interstimulus relations can estimate the contribution to acquisition by a number of processes, there are additional processes which rely upon the integrity of the entire reinforced serial compound.

Perceptual Integration

Perceptual integration of the compound differs from associative transfer between CSB and CSA. Instead, CSB may be thought to "bridge" the longer CSA-US interval, effectively shortening it and thus facilitating direct conditioning of CSA (Kehoe et al., 1981a; Rescorla, 1982). Conversely, other perceptual hypotheses have argued that responding to CSB will suffer a generalisation decrement when tested outside the stimulus context of the compound (e.g., Borgealt, Donahoe & Weinstein, 1972; Hancock, 1982; Kehoe, 1979; Rescorla, 1972b; Wickens, 1959, 1965). Under a generalisation decrement hypothesis, responding to the initial portion of CSA would not be subject to a generalisation decrement during testing, because the perceptual encoding of CSA is affected only by the static background stimuli which remain the same whether or not CSA is subsequently presented.

Discrimination Mechanisms

The simplest discrimination hypotheses contend that response acquisition to CSA may be facilitated if CSB fills an otherwise "empty" interval between CSA and the US because the reinforced trial will be more distinguishable from the background stimuli (Bolles, Collier, Bouton & Marlin, 1978; Kaplan & Hearst, 1982; Mowrer & Lamoreaux, 1951). In contrast, advocates of temporal discrimination hypotheses contend that a serial compound may hinder response acquisition to CSA and perhaps facilitate responding to CSB. These hypotheses argue specifically that the sequence of discrete stimuli in a serial compound enhances the precision with which a response can be placed just prior to the onset of the reinforcing event (Sears, Baker & Frey, 1979; Williams, 1965).

Competition Hypotheses

Competition hypotheses contend that there is a trade-off between concurrent stimuli in their respective associative strengths (Frey & Sears, 1978; Rescorla & Wagner, 1972; Revusky, 1971; Sutton & Barto, 1981) or attentional strengths

(Mackintosh, 1975; Mackintosh & Reese, 1979; Moore & Stickney, 1980; Sutherland & Mackintosh, 1971). Competition hypotheses can account for a variety of outcomes depending on the parameters determining the relative competitive advantages of CSA and CSB. Selective attention hypotheses (e.g., Sutherland & Mackintosh, 1971) would predict that response acquisition to CSB will be hindered if CSA and its traces capture the attention of the subject, thus precluding full attention to CSB even though it is closer to the US (Kehoe, 1979; Kehoe, Schreurs & Amodei, 1981b). However, if attention to CSA wanes before CSB appears, then CSB may be able to attract attention to itself and away from CSA, thus hindering response acquisition to CSA (Mackintosh & Reese, 1979). Other major competition hypotheses generally predict that response acquisition to CSA will be impaired more than CSB in serial compound conditioning (Mackintosh, 1975; Rescorla & Wagner, 1972; Revusky, 1971, p. 171). In general, these latter competition hypotheses contend that the associative strengths which accrue to each CS depend on their relative associative strengths at the time of US occurrence. Since CSB is closer to the US, it would gain associative strength faster than CSA and would thereby gain a competitive advantage over CSA.

Information Hypotheses

Information hypotheses predict that response acquisition to CSB will suffer as a consequence of serial compound training (Cantor, 1981; Cantor & Wilson, 1981; Egger & Miller, 1962; Seligman, 1966). According to Egger and Miller's original hypothesis, if CSA and CSB are equally reliable "predictors" of the US, then associative strength will accrue to the initial CSA and not the later "redundant" CSB. The more recent information hypotheses contend that CSB will lose its effectiveness in gaining access to the associative apparatus if its occurrence is well predicted by preceding events, namely CSA (Cantor, 1981, p. 313; Cantor & Wilson, 1981, p. 262; cf. Pearce & Hall, 1980, p. 535; Wagner, 1978). In the case of Cantor and Wilson's (1981) hypothesis, they imply that response acquisition to CSA may be facilitated by the ability of CSA to predict CSB even though this predictive CSA-CSB relation would impair the acquisition to CSB. Thus, in a sequence of optimally separated CSs, the earliest stimulus would gain maximal associative strength and the remaining elements would gain less associative strength.

EMPIRICAL REVIEW

The diverse body of research devoted to serial compound conditioning can be organised around manipulations of the CSA-US, CSB-US, and CSA-CSB relations. Some of the manipulations have been parametric in nature, e.g., CSA-CSB interval. However, many important studies have used a single compound and focused on analytic comparisons with various control conditions, especially single-stimulus training conditions which provide the baseline against which interactions between CSA and CSB can be detected. Although the CSA-US, CSB-US, and CSA-CSB relations are conceptually separable, it is not possible to vary each of them separately within the context of a compound. For example, a parametric manipulation of the CSA-US interval will also manipulate the CSA-CSB interval if the CSB-US interval is held constant. Likewise, removing the CSA from the compound will eliminate both the CSA-US and CSA-CSB relation, leaving only the CSB-US relation intact. Thus, the inclusion of each study under a particular heading in the following review reflects an expository convenience rather than a logical necessity.

CSA-US Relation

Much of the interest in serial compounds stems from observations which suggest that the associative effects of the contiguous CSB-US relation are hindered by the CSA-US relation, even though CSA has a more remote temporal relation to the US

(e.g. Egger & Miller, 1962; Wickens, 1959). Rigorous demonstrations which include a single-stimulus CSB-US control have been conducted in taste aversion learning (Bond, in press; Revusky, 1971, pp. 192-197) and in conditioning of the rabbit's nictitating membrane response (Kehoe, 1979, in press; Kehoe, Gibbs, Garcia & Gormezano, 1979, Experiment 2). In these studies, it was found that, under some parametric conditions, responding on CSB test trials after serial compound training was lower than after CSB-US training alone. Since these studies included manipulations of the CSA-CSB and CSB-US relations, their details will be described in later portions of this review.

Partial Reinforcement of CSA

In one of the earliest and best-known studies of serial compound conditioning, Egger and Miller (1962) presented to rats an overlapping serial compound paired with a food US. In subsequent extinction testing, Egger and Miller found that CSB by itself had less secondary reinforcing power for barpress responding than did CSA. Even though CSB was more contiguous to the US than was CSA, the level of responding produced by CSB did not exceed that produced by a control stimulus which had been explicitly unpaired with food. Consequently, Egger and Miller concluded that the early and reliable prediction of the US by CSA made the later CSB a redundant predictor of the US and precluded CSB from gaining associative strength (cf. Hancock, 1982). To test their information hypothesis, Egger and Miller manipulated the CSA-US relations by interspersing presentations of CSA-alone among the CSA-CSB-US presentations. Thus, CSA became an unreliable predictor of the US and, conversely, CSB became the more reliable predictor of the US even though its relation to both the CSA and US in the serial compound was unchanged. In agreement with Egger and Miller's expectations, CSB was found to have acquired substantial secondary reinforcing value. This partial reinforcement of a CS as a means for manipulating the relative predictive value of CSs has spawned substantial research with simultaneous compounds (e.g., Wagner, 1969a, 1969b, 1969c; Wagner, Logan, Haberlandt & Price, 1968), but there does not appear to be any comparable research with serial compounds.

Pretraining of CSA

There has been a series of recent studies in which CSA-US training was conducted and then CSB was added to form the serial compound. Thus, this procedure was identical to that for blocking of response acquisition to an added CS in a simultaneous compound. Studies of blocking with simultaneous compounds have provided some of the most compelling evidence for interactions between CSs which override contiguity-based processes of association (Mackintosh, 1975; Rescorla & Wagner, 1972; Sutherland & Mackintosh, 1971). In particular, blocking has not been easily attributed to a generalisation decrement in transfer from compound training to testing of the added CS. On a routine basis, investigations of blocking have compared responding to the added CS in a blocking group to that in a control group given training with only the compound. These studies have shown that the impairment in acquisition to the added CS in a blocking group exceeds any detrimental effects of compound training including any deficits in transfer from the compound to the individual CSs (e.g., Kamin, 1969; Marchant & Moore, 1973). However, among serial compound conditioning studies, pretraining of CSA in a serial compound has produced some results which challenge the conventional interpretations of blocking.

The most interesting results have been obtained in studies conducted by Gaioni (1982) using the conditioned suppression paradigm and by Kehoe et al. (1981b) using the rabbit nictitating membrane response (NMR) preparation. Gaioni (1982, Experiment 1) first paired a 3-min CSA with a shock US and then added a 30-sec CSB

just before the US. Similarly, Kehoe et al. (1981b) paired an 800-msec CSA with a shock US and then added a 400-msec CSB. In both studies, test trials with CSB revealed profound blocking relative to a compound-trained control group. At first blush, these findings appear consistent with blocking effects obtained with simultaneous compounds. However, Gaioni examined the pattern of suppression inside the serial compound of the blocking group and found that suppression became progressively localised to the CSB segment, a pattern more similar to that found in the serial compound control group than a CSA-US control group. Moreover, Gaioni was able to demonstrate that it was the presence of the added CSB, not the passage of time since CSA onset, which controlled the observed suppression. Specifically, by delaying the onset of CSB on certain compound test trials, Gaioni produced a corresponding delay in the suppression of responding. In subsequent experiments, Gaioni used a CSA of variable duration and confirmed (a) the blocking effect on CSB test trials and (b) the progressive localisation of conditioned suppression to CSB inside the compound. Thus, Gaioni's findings indicate that substantial associative strength accrued to CSB inside the stimulus context of the serial compound, while the pretrained stimulus, CSA, clearly lost the ability to produce suppression by itself. However, Gaioni's (1982) provocative results await confirmation. On the one hand, Kehoe et al. (1981b) found high levels of responding throughout CSA in all groups and did not observe any alteration in the temporal pattern of CR initiation when CSB was added. On the other hand, other investigations have revealed that the addition of CSB detracts from responding to CSA. Unfortunately, these studies did not examine responding to CSB to ascertain whether or not the blocking result would occur when the same CSB was tested outside the compound (Levis, Dubin & Holzman, 1978; Brodigan & Trapold, 1974).

Extinction of CSA

The effects of extinguishing CSA have been examined by Holland and Ross (1981, Experiments 2b and 3). They found that, with rats, a light-tone-food sequential compound produced acquisition of a "head jerk" generally directed toward the food magazine. Extinction of this response to CSA produced a reduction in the likelihood of similar responses to CSB when tested in extinction. By using a within-subjects design in which rats were trained with two different serial compounds, Holland and Ross (1981, Experiment 3) showed that the deleterious effects of extinction with CSA were specific to the CSB previously paired with CSA . Consequently, Holland and Ross concluded that there was a direct association between CSA and CSB such that alterations in responding to either of them would have similar consequences for the other.

CSB-US Relation

Analytic Demonstrations

The simplest manipulation of the CSB-US relation is to remove CSB from a serial compound creating a single-stimulus CSA-US condition which lacks not only CSB but also its interrelations with both the US and CSA. Comparisons between serial compound and CSA-US conditions have been conducted in all the major conditioning preparations. CSB usually facilitates response acquisition to CSA although some notable exceptions have occurred.

Conditioned Suppression. There have been systematic demonstrations in conditioned suppression paradigms that a serial compound facilitates the rate of acquisiton to a trace CSA (Bolles et al., 1978; Kamin, 1965, p. 146; Pearce et al. 1981). The earliest report of facilitation in a serial compound may be found in a brief description of an experiment conducted by Kamin (1965, p. 164) in which he

compared three groups of rats. One group received reinforced presentations of a serial compound consisting of a 90-sec CSA (e.g., noise) followed by a 90-sec CSB (e.g., light). There were two CSA-US control groups. In one control group, the gap between the offset of CSA and the onset of the US was left empty, thus creating a CSA trace conditioning procedure. However, in the other control group, CSA was extended to fill the entire CSA-US interval creating a CSA delay conditioning procedure. Kamin found that the level of barpress suppression to CSA in the serial compound was higher than that of the CSA trace conditioning control but lower than that of the CSA delay conditioning control. During CSB in the serial compound, substantial suppression occurred, which was greater than that of the comparable period in the CSA trace conditioning control but equal to that of the comparable period in the CSA delay conditioning control. Recently, experiments using both off-baseline procedures (Bolles et al., 1978, Experiment 1) and on-baseline procedures (Pearce et al., 1981, Experiments 1, 2, and 3) have confirmed Kamin's findings that the presence of CSB in a sequential compound facilitates the rate of acquisition to CSA relative to a CSA trace control but not a CSA delay control. In terms of asymptotic level of responding, Bolles et al. (1978) found that after 64 trials all three conditions produced a modest level of suppression to CSA. In the case of Pearce et al.'s results, all three conditions ultimately produced complete suppression.

Whereas facilitation of acquisition to CSA in a sequential compound occurs over relatively small numbers of training trials, more prolonged training in barpress suppression appears to produce a decline in responding to CSA suggesting that CSA will ultimately acquire an inhibitory potential (Brahlek, 1968). Specifically, Bolles et al. (1978) used a maximum of 64 trials and Pearce et al. (1981, Experiment 1) used a maximum of only 20 trials. In contrast, Brahlek (1968) continued conditioned suppression training for 432 trials. As in previous experiments, there was a sequential compound group, a CSA trace group, and a CSA delay group. Initially, all of Brahlek's groups showed equally rapid acquisition of suppression to CSA. Throughout training, the CSA delay group showed nearly total suppression for the entire CS-US interval. For the initial 90 trials, both the serial compound and CSA trace groups showed more suppression to CSA than during CSB or the trace interval, respectively. Thereafter, suppression to CSA diminished gradually, while suppression during the second segment of the CS-US interval increased.

Even without extensive training, impairment of response acquisition to CSA can result from serial compound training. Specifically, Mackintosh and Reese (1979) have examined conditioned suppression of licking in the rat. One group was given a single exposure to a sequential compound consisting of a 15-sec tone, a 15-sec light, and a 15-sec trace interval prior to a shock US. In addition to the serial compound group, there was a CSA trace group and a group which received exposure to a simultaneous tone-light compound. Tests with CSA revealed that the rats in the CSA trace group and in the simultaneous compound group showed nearly complete suppression (mean ratio = .08), while the rats trained with the serial compound showed only a moderate suppression of licking (mean ratio = .22).

Conditioned reflex preparations. Studies entailing direct measurements of conditioned responses have yielded substantial facilitation of response acquisition to CSA in a serial compound far in excess of what would be obtainable in either CSA trace or CSA delay conditioning procedures. Conversely, there is also evidence that response acquisition to CSA can be impaired under certain circumstances. Analytic studies with CSA-US controls have been carried out in the canine salivary preparation (Williams, 1965), the rabbit NMR preparation (e.g., Kehoe et al., 1979), and rabbit eyelid response preparation (Sears et al., 1979).

Facilitation of response acquisition to CSA in a serial compound has been obtained repeatedly in the rabbit NMR preparation (Gibbs, 1979; Gormezano &

Kehoe, in press; Kehoe et al., 1979; Kehoe et al., 1981a). Moreover, the facilitation has appeared most clearly when CSA is well removed from both CSB and the US. For example, Kehoe et al. (1979, Experiment 2) conducted training with a serial compound consisting of a 400-msec tone, a 2,000-msec "trace interval" and a 400-msec light which overlapped the 50-msec shock US. Thus, the CSA-US interval was 2,750 msec, and the CSA-CSB interval was 2,400 msec. The experiment also included a corresponding CSA trace group trained with the 2,750-msec CSA-US interval. In the serial compound group, the level of responding to CSA rose over the course of 360 trials to a maximum level near 80% CRs. The maximum level of responding to CSA far exceeded the asymptotic level of responding in the CSA trace group, which reached only 25% CRs. Although Kehoe et al.'s experiments did not contain a CSA delay control, the level of responding to CSA in the serial compound condition was far above the levels obtained in comparable delay conditioning procedures (Schneiderman & Gormezano, 1964; Kehoe, 1979; Schneiderman, 1966). However, the maximum level of responding to CSA was not permanently sustained. In a manner similar to that seen by Brahlek (1968) in conditioned suppression, responding to CSA began to decline slowly after reaching its maximum level.

At shorter CSA-US intervals, the sum of the results suggests that CSB has little effect on acquisition of the rabbit NMR to CSA. Kehoe et al. (1979, Experiment 2) used an 750-msec CSA-US interval and a 350-msec CSB-US interval in a tone-light sequential compound. They found that the level of responding to CSA reached an asymptotic level of 80% CRs, which was significantly lower than that of the corresponding CSA-US control. However, Kehoe (in press) found, in a similar overlapping compound, one instance of a slight but significant facilitation of CR acquisition to CSA and three instances in which there was no effect on acquisition to CSA.

Other conditioned reflex studies have found more definitive evidence that CSB can impair CR acquisition to CSA in a serial compound. Williams (1965) examined salivary conditioning in four dogs, which were trained with a sequential compound consisting of a 16-sec CSA followed by a 6-sec CSB, the last 2 sec of which overlapped presentation of a food pellet. As within-subject controls, two dogs were given reinforced training with a 22-sec CS in the same modality as CSA and the two other dogs were given CSB-US pairings outside the compound. Measurements of the momentary rate of salivation indicated that, at asymptote, responding to CSA in the compound fell below that observed during the corresponding period in the 22-sec control CS. Conversely, the rate of salivation during CSB in the serial compound exceeded that during the corresponding period in the 22-sec control CS. Moreover, the rate of salivation to CSB in the serial compound exceeded that on CSB-US trials outside the compound. Williams (1965, pp. 351-353) concluded that an inhibitory potential had accrued to CSA in the serial compound and that the enhanced level of responding to CSB inside the compound represented a positive induction from the inhibitory CSA (cf. Pavlov, 1927, pp. 188-196).

Frey and his associates have recently used the rabbit eyeblink preparation in obtaining data that suggest the joint operation of facilitatory and inhibitory processes in a serial compound. Specifically, Sears et al. (1979, Experiments 1, 2, and 3) used a sequential compound consisting of 800-Hz and 3,000-Hz tones. The CSA-US interval was varied over a range between 500 and 1,100 msec, while the CSB-US interval was manipulated over the range of 200 to 700 msec. In all serial compound conditions, the level of responding during CSA was very low (less than 20% CRs) and did not exceed the level of responding produced by corresponding CSA trace controls (Sears et al., 1979, Experiment 3). In agreement with Williams' (1965) observations, CRs in the serial compound condition tended to be more concentrated just prior to US onset in the serial compounds than they were in corresponding CSA control conditions (Sears

et al., 1979, Experiment 3). However, Sears et al. obtained some indirect indications that CSA in the serial compounds did acquire associative strength. Specifically, Sears et al. (1979, Experiments 1 & 2) conducted savings tests by pairing CSA with the US at an efficacious CS-US interval. The savings tests revealed that the rate of CR acquisition to CSA was inversely related to the CSA-US and CSB-US intervals which had been confounded during serial compound training. Unfortunately, Sears et al. failed to include any sort of rest control group to provide a baseline against which to assess transfer. In addition to the savings tests, latent response-evoking characteristics of CSA were assessed by presenting it prior to a US of threshold intensity. In general, the presentation of CSA enhanced the amplitude of the UR to the weak US. However, in the absence of a rest control, the enhancement of UR amplitude by CSA may only be an instance of similar effects which have been obtained with novel CSs in the rabbit NMR preparation (Ison & Leonard, 1971; Thompson, 1976). More importantly, the form of the UR was altered by the presentation of CSA. Specifically, the peak of the UR, which ordinarily occurred within 100-200 msec after US onset, was shifted to a location near the point in time at which the US would have occurred relative to CSA onset during serial compound training. CSA's ability to shift the peak of the UR toward the previous locus of the US provides some evidence that potential facilitation of overt responding to CSA may be masked by inhibitory mechanisms, e.g., "temporal discrimination" (cf. Williams, 1965).

Appetitive conditioning preparations. In studies using autoshaping and other appetitive conditioning procedures, CSB has facilitated response acquisition in serial compounds. In autoshaping of the pigeon's keypeck, Ricci (1973) compared sequential compounds composed of four different key colours to CSA delay conditioning. For a total CS duration of 120 sec, the serial compound produced more rapid response acquisition than the CSA delay control group. However, for a total CS duration of 30 sec, both the serial compound and CSA delay control condition produced very rapid response acquisition. Similarly, Newlin and LoLordo (1976, Experiment 1) compared a group trained with an 8-sec sequential compound of two different key colours, a CSA trace group, a CSA delay group, and a CSB-US conditioning group. Although Newlin and LoLordo's stimulus durations were much shorter than those of Ricci (1973), the serial compound still produced the fastest CR acquisition to a criterion of 5 consecutive trials with a peck (median = 28 trials), which was followed by that of the CSB control group (median = 58 trials). The CSA delay and CSA trace groups required medians of 73 and 269 trials to attain the acquisition criterion. Neither study reported the likelihood of responding to CSA but descriptions of the pattern of pecks across the CS-US interval reveals that animals in the serial compound groups tended to concentrate their pecks in the latter portions of the compound rather than CSA. In contrast, the animals in the CSA delay condition distributed their pecks more evenly over the CS-US interval. However, since there were multiple pecks during a trial, it is not possible to ascertain what the likelihood of a peck or the rate of pecking was during CSA.

Since Newlin and LoLordo's study, three different studies have shown that the presence of CSB in a serial compound facilitates response acquisition to CSA (Holland & Ross, 1981; Kaplan & Hearst, 1982; Rescorla, 1982). First, Holland and Ross (1981) found that, with rats, a light-tone-food sequential compound produced acquisition to CSA of a "head jerk", while there was no discernable acquisition of the head jerk to CSA in a control condition consisting of interspersed CSA-US and CSB-US trials. Second, Kaplan & Hearst (1982, Experiments 1 & 2) used pigeons and compared acquisition of approach to a 12-sec CSA (green keylight) in sequential compound groups relative to a CSA trace control group. They found that approach to CSA was facilitated by any one of a variety of CSBs during a 12-sec trace interval prior to food presentation. The CSBs included a white key, overhead lights and an auditory clicker. Furthermore, facilitation was obtained whether CSB entailed the onset of a

discrete stimulus event or the offset of a stimulus condition which had filled the intertrial interval (Kaplan & Hearst, 1982, Experiment 2). Third, Rescorla (1982) demonstrated facilitation of autoshaped keypecking in pigeons using within-subject designs (cf. Williams, 1965). CSA in the serial compound and trace conditioning control were distinctively coloured keylights, and CSB was either another keylight (Experiment 1) or a tone (Experiment 2). Both of the latter studies entailed extensive training, i.e., 816 trials (Kaplan & Hearst, 1982, Experiments 1 and 2) and 336 trials (Rescorla, 1982, Experiment 1), respectively. Over the course of training, neither study revealed any declines in the maximum level of responding to CSA.

Taste aversion learning. Research using taste aversion learning has most consistently demonstrated that the presence of CSB impairs the level of acquisition to CSA (Bond, in press; Der-Karabatien & Gorry, 1974; Kalat & Rozin, 1971; Revusky, 1971). For example, Revusky (1971, pp. 189-191) presented a sequential compound consisting of a 2-ml saccharine solution (CSA), a 15-min gap, and a 5-ml solution of vinegar (CSB) followed by an injection of lithium chloride an hour later. A CSA control group received the same treatment except that exposure to plain water was substituted for CSB. In subsequent preference tests for the CSA solution versus a novel coffee-flavoured solution, the rats in the serial compound groups generally showed a weaker conditioned aversion to CSA than did the CSA control group. However, the level of aversion to CSA in the serial compound groups was still greater than in a further control condition which did not receive the LiCl injection following presentation of the serial compound.

CSB-US Manipulations Outside the Compound

Subsequent to demonstrations that the presence of CSB alters the level of response acquisition to CSA in a serial compound, a number of investigations have manipulated the level of responding to CSB outside the compound to determine what effects it would have on the level of responding to CSA alone or as part of a serial compound. In brief, these studies have revealed that (1) stimulus generalisation from CSB-US training to tests with CSA is usually low, (2) prior training of CSB usually blocks response acquisition to CSA in a serial compound, and (3) extinction of CSB after serial compound training has widely divergent effects on the level of responding to CSA.

Cross-modal transfer. Kehoe et al. (1979) examined the contribution of cross-modal generalisation from CSB to CSA as a source of response acquisition to CSA in a serial compound. Kehoe et al. (1979, Experiments 2 and 3) trained rabbits with a light CSB and then periodically presented a tone CSA. The mean level of responding on CSA test trials never exceeded 25% CRs which was well below the maximum levels of responding to CSA, i.e., in excess of 80% CRs. Moreover, Kehoe et al. (1979, Experiment 3) examined response acquisition to CSA in groups which received "uncoupled" training in which the CSA-US and CSB-US trials were intermixed. This control condition provided a joint estimate of stimulus generalisation from CSB to CSA, direct CSA-US conditioning, and any general transfer, e.g., learning to learn. It was found that the level of responding to CSA in the uncoupled training condition was significantly lower than that produced by serial compound conditioning. Similar studies in conditioned suppression (Pearce et al., 1981, Experiments 3 & 5) and in appetitive conditioning (Holland & Ross, 1981; Rescorla, 1982, Experiments 1 & 2) have found that uncoupled training of CSA-US and CSB-US produced slower acquisition of responding to CSA than did serial compound training.

Prior training with CSB. Training with CSB prior to serial compound training provides conditions which could either facilitate response acquisition to CSA or impair response acquisition to CSA. On the one hand, CSB-US training followed by CSA-CSB-US training has all the features of second-order conditioning except that in

true second-order conditioning the CSA-CSB series is presented without the US. On the other hand, the addition of CSA to CSB-US to form a compound has all the features of a blocking procedure. The available data indicate that prior training of CSB partially blocks response acquisition to CSA in a serial compound. Specifically, partial blocking of response acquisition to CSA has been reported in taste aversion learning (Revusky, 1971, pp. 197-203), odor aversion learning (Cheatle & Rudy, 1978), conditioned suppression (Pearce et al., 1982, Experiment 3), but not in conditioned activity (Holland, 1980, Experiment 1). In the rabbit NMR preparation, Gibbs (1979) produced partial blocking of CR acquisition to CSA when the CSA-CSB interval was 1600 msec, but Kehoe et al. (1981b, Experiment 3) found only a transitory and nonsignificant impairment in acquisition to CSA when the CSA-CSB interval was 400 msec. Even partial blocking of CSA provides strong evidence for processes of competition among stimuli for attention or associative strength. There is no possibility that generalisation decrement is the source of the low level of responding to CSA because testing of CSA occurs without any changes in the preceding stimulus context.

Although Holland (1980, Experiment 1) failed to observe overall blocking of response acquisition to CSA, he claims that the presentation of the US in the serial compound impairs second-order conditioning between CSA and CSB. In Holland's experiments, all rats were given initial reinforced training with a light CSB which was continued into later training phases in "refresher" trials. Holland (1980, Experiment 1) subsequently split his subjects into three groups: a serial compound group (CSA-CSB-US), a second-order conditioning group (CSA-CSB), and a CSA trace conditioning group (CSA-US). During the training phase, the serial compound group showed as much activity during CSA as the CSA-trace conditioning group, both of which showed more activity than the second-order conditioning group. Thus, there was no evidence of either blocking or facilitation of acquisition to CSA in the serial compound as compared to the CSA-trace control. However, Holland (1980) conducted extinction testing with CSA after the rats had been either food satiated or re-deprived. The logic behind the manipulation of food deprivation rested on the premise that food satiation would debilitate any first-order CSA-US association in the serial compound group but would not affect second-order CSA-CSB or CSA-R associations reinforced by CSB (cf. Holland & Rescorla, 1975). When the rats were satiated, subjects in the serial compound and CSA-trace conditioning groups showed lower levels of responding than the second-order conditioning group (Holland, 1980, Experiments 1 & 2). However, after re-deprivation the rats in the serial compound condition showed a higher level of responding to CSA than in the second-order conditioning group (Experiment 2).

Post-training manipulations of CSB. Manipulations with CSB following serial compound training, e.g. extinction of CSB, have been used to determine whether or not responding to CSA is autonomous of the CSB-US association (cf. Rizley & Rescorla, 1972). In brief, extinction of CSB has generally reduced the level of responding to CSA. In the earliest study of this sort, Boyd and Levis (1976) conducted one-way avoidance training of rats with a sequential compound consisting of tone, noise, and buzzer. Different groups were subsequently given forced exposure to either the first stimulus, second stimulus, third stimulus, or background stimuli. In extinction testing with the entire compound, the groups exposed to the third stimulus showed faster extinction of avoidance responding to the earlier as well as later components of the sequential compound. Because extinction of responding to the earlier components occurred prior to any further exposures of the third stimulus, the effect was attributed to a loss of generalised fear. However, Boyd and Levis' (1976) results can also be construed as indicating that the fear CRs to the early components depended on an S-S-shock or S-S-R connection mediated by the third stimulus (cf. Holland & Rescorla, 1981; Rizley & Rescorla, 1972). Subsequent investigations with

appetitive conditioning of "head-jerk" responses in the rat (Holland & Ross, 1981, Experiments 2A and 3) and conditioning of the rabbit NMR (Gormezano and Kehoe, in press) have that found that extinction of responding to CSB produced immediate reductions in the level of responding to CSA. Moreover, Holland and Ross (1981, Experiment 3A) used a within-subjects design to show that the deleterious effects of extinguishing CSB were specific to CSA and, thus, were more than generalised extinction effects. In conditioned suppression of barpressing in rats, Pearce et al. (1981, Experiment 2) found that unreinforced presentations of CSB during training reduced the level of responding to CSA in the serial compound. In contrast, Rescorla (1982, Experiment 3) reports that, in autoshaping of pigeon's keypeck, extinction of CSB failed to reduce the rate of responding to CSA after serial compound conditioning. Likewise, in a lick-suppression procedure, manipulation of the CSB-US association either by extinguishing CSB or by raising the intensity of the US paired with CSB failed to affect the level of suppression to CSA (Pearce et al., 1981, Experiment 5). While similar manipulations of the first-order CS after second-order conditioning have also produced inconsistent results across paradigms, the inconsistencies do not appear to be parallel to each other when one compares serial compound and second-order conditioning outcomes. Whereas Pearce et al. (1981, Experiment 2) found that unreinforced presentations of CSB reduced the magnitude of barpress suppression to CSA, Rizley and Rescorla (1972) found that extinction of a first-order CS failed to affect barpress suppression to the second-order CS. A closer parallel in procedure can be found in the autoshaping literature. Whereas Rescorla (1982, Experiment 3) found that extinction of CSB failed to lower responding to CSA, second-order conditioning studies of autoshaping have shown that extinction of the first-order CS reduces responding to the second-order CS (Rashotte, Griffin & Sisk, 1977; Rescorla, 1979).

CSB Inside Serial Compounds

CSB-US interval. Manipulations of the CSB-US interval have revealed that it determines the rate of CR acquisition to CSA and the serial compound as a whole. Moreover, the CSB-US relation appears to be effective inside the serial compound even when test trials outside the context evoke only a low level of responding to CSB. Specifically, Frey et al. (1971) found that for a serial compound of two diffferent tones, the CSB-US interval determined the acquisition rate of conditioned eyeblink in the rabbit. However, Frey et al. did not include test trials with either CSA or CSB. More recently, test trials with CSA and CSB were included in investigations of the rabbit's NMR to a variety of serial compounds (Kehoe, 1979; in press; Kehoe et al., 1981a). Specifically, Kehoe (1979) used a tone-light sequential compound and manipulated the CSB-US interval across the values of 200, 400, 800, and 1600 msec. Furthermore, the CSA-US/CSA-CSB interval was manipulated in an orthogonal fashion. At each level of the CSA-US/CSA-CSB interval, the rate of CR acquisition to both the compound and CSA decreased as the CSB-US interval increased. Yet, test trials with CSB produced a uniformly low level of responding which was less than that of corresponding single-stimulus controls for all but the 1600-msec CSB-US interval (Kehoe, 1979). Since the arrangement of stimuli in a strictly sequential compound confounds the CSB-US interval with the interval between the offset of CSA and the onset of the US, Kehoe (in press) re-examined the effects of the CSB-US interval in a serial overlapping compound where the CSA-US interval was held constant at 800 msec while the CSB-US interval was varied over the values of 400, 600, and 800 msec. Thus, the interval between CSA offset and the US was constant at a value of zero, while the CSA-CSB intervals were 400, 200, and 0 msec, respectively. Again, the rates of CR acquisition to CSA and the serial compound were inversely related to the CSB-US interval and the level of responding on CSB test trials was still lower than in single-stimulus controls.

Whereas Kehoe (1979; in press) examined responding in compounds in which the CSA-US intervals themselves were capable of sustaining high levels of CR acquisition, Kehoe et al. (1981a, Experiment 3A) examined the effects of the CSB-US interval in sequential compounds containing a long CSA-US interval which itself produced negligible conditioning. Specifically, the CSA-US interval was 2,800 msec, CSA duration was 400 msec, and the CSB-US interval was varied over the values of 0, 80, 160 and 360 msec. Thus, there was some small variation in the CSA-CSB intervals, which ranged from 2,800 msec to 2,480 msec. It was found that the manipulation of the CSB-US interval had parallel effects on the level of responding to CSA and CSB. The 0-msec CSB-US interval produced no discernible conditioning to either CS but the rate and level of CR acquisition to CSA and CSB rose as the CSB-US interval increased to 360 msec which is near the optimal value for the rabbit NMR preparation (cf. Gormezano, 1972).

Other investigators have also manipulated the CSB-US interval in the context of a fixed CSA-US interval (Kaplan & Hearst, 1982; Pearce et al., 1981, Experiment 4; Rescorla, 1982, Experiment 1). In these cases, the investigators were interested solely in the effects on responding to CSA and regarded the manipulation as one of the CSA-CSB relationship. Accordingly, their findings will be treated in connection with manipulations of the CSA-CSB interval.

CSB salience. In an effort to delineate the relation between overshadowing and serial compound conditioning, manipulations of CSB salience have been conducted in taste aversion learning (Revusky, 1971, pp. 189-191) and rabbit NMR conditioning (Kehoe, in press). Revusky (1971) found that the magnitude of a taste aversion to a saccharine solution (CSA) progressively decreased when followed by solutions with increasing concentrations of vinegar (CSB), i.e., CSA was subject to overshadowing by CSB. Since CSB was not tested, it is unknown whether there was a reciprocal overshadowing of CSB. In the case of the rabbit NMR preparation, Kehoe (in press) found that CR acquisition to a light CSA showed no impairment regardless of a tone CSB's intensity. CR acquisition to the compound as a whole and to CSB was positively related to the CSB intensity. However, at all CSB intensities, the level of responding on CSB test trials showed impairments relative to single-stimulus controls. What is most notable is that the most intense tone was one which had overshadowed the light in a simultaneous compound. Apparently, the temporal primacy of the light CSA gave it the ability to impair CR acquisition to CSB, even though CSB was otherwise a known overshadowing stimulus.

Measurements of CSB's Associative Strength

A substantial number of attempts have been made to determine whether a low level of responding on CSB test trials following serial compound training represents an actual deficit in the acquisition of associative strength (e.g., Egger & Miller, 1962) or a generalisation decrement, i.e., an incomplete transfer of associative strength from the stimulus context of the compound (e.g., Borgealt et al., 1972; Wickens, 1959). One line of research has focused on the relative levels of responding to CSA and CSB and more recent experiments have attempted to manipulate the likelihood of generalisation decrement on test trials. Other lines of research have attempted to determine the associative strength of CSB inside the stimulus context of the compound by (1) measurements of the temporal pattern of responding inside the compound and (2) comparisons of the level of responding during CSB inside the compound with the level of responding on CSB test trials outside the context of the compound.

Comparisons of responding to CSA and CSB. Following Egger and Miller's (1962) pioneering study, a number of studies used a single type of serial compound and compared the relative level of responding to CSA and CSB. It became clear that the

associative effects of the contiguous CSB-US relation are not always superseded by the temporal primacy of CSA. In an experiment using secondary punishment with rats, Seligman (1966) found that some associative strength did accrue to CSB relative to an unpaired control. Seligman (1966) consequently proposed a "weak" information hypothesis which contended that the relative contiguity of CSB to the US would partially offset the deleterious effects of CSB's redundancy. There have since been repeated observations that the response strength of CSB on test trials can equal and even exceed that of CSA in secondary reinforcement procedures with rats (Baker, 1972; McCausland, Menzer, Demsey & Birkimer, 1967), in secondary reinforcement with pigeons (Hancock, 1982; Thomas, Berman, Serednesky & Lyons, 1968), and in conditioned suppression with rats (Ayres, 1966; Borgealt et al., 1972). Although a high level of responding to CSB relative to CSA can be used to challenge information hypotheses, the comparison between the levels of responding to CSA and CSB provides little basis for further, more positive conclusions. Since these studies did not include single-stimulus controls, it is not clear whether the relative levels of responding to CSA and CSB reflect interactions affecting CSA, CSB, both CSs or neither CS.

Two studies have attempted to manipulate the likelihood of generalisation decrement from serial compound training to CS testing. In a secondary reinforcement study closely patterned after that of Egger and Miller (1962), Baker (1972) varied the degree of overlap between CSA and CSB, which could alter the potential influence of CSA and its traces on CSB (cf. Hancock, 1982; Kehoe, 1979). He found that, as overlap decreased, the absolute reinforcing effect of CSA decreased and the reinforcing effect of CSB increased. Recently, Hancock (1982) tried a different tactic. Rather than trying to minimise the generalisation decrement for CSB, he attempted to the equate the possible generalisation decrements for CSA and CSB on their respective test trials. In one experiment, pigeons received secondary reinforcement training in which keypecking on a VI schedule led to a sequential compound of two different colours on a keylight followed by food. The keylight during the intertrial interval was a distinctive colour for the experimental group and white for the control group. The birds were tested to determine whether pecking on a white key would be reinforced more greatly by presentations of CSA or CSB. In the case of the experimental group, the white key was a new stimulus condition. Thus, the subsequent presentation of either CSA or CSB would presumably suffer the same degree of generalisation decrement. In the case of the control group, CSA had always been preceded by a white key, and thus, the reinforcing properties of CSA would not be expected to suffer a generalisation decrement. Since CSB had always been preceded by a coloured key, testing of CSB following a white key would be subject to a generalisation decrement equivalent to that in the experimental group. Hancock (1982) found that, in the experimental group with equal possible generalisation decrements, the mean level of responding maintained by CSB was significantly greater than that of CSA. The level of responding maintained by CSB in the control group appeared equal to that of CSB in the experimental group. However, in the control group, the level of responding maintained by CSA (which could not have suffered a generalisation decrement) showed a higher level than that of CSA in the experimental group. Subsequently, Hancock (1982, Experiment 2) used a two-key choice test and showed that, when CSB and CSA were subject to equal generalisation decrements, the pigeon's pecking was more strongly reinforced by CSB than by CSA.

Responding to CSB inside the serial compound. Measurements of the temporal pattern of responding inside a sequential compound have indicated that the presence of CSB tends to sharpen the temporal gradient of responding in the direction of CSB and the US. Such sharpened gradients have been obtained in canine salivary response conditioning (Williams, 1965), autoshaping (Newlin & LoLordo, 1976; Ricci, 1973), and conditioned suppression (Gaioni, 1982). Similarly, it has long been noted in operant fixed interval schedules that the addition of a "clock", which can be viewed as

a sequential stimulus, substantially sharpens the gradient of responding across the interval between reinforcements (Ferster & Skinner, 1957, pp. 266-301). With the exception of Gaioni's (1982) experiments, these studies have not usually included test trials with CSB to determine whether the level of responding to CSB by itself would show deficits. In other studies where CSB test trials have been used, comparisons between the absolute level of responding during CSB inside a serial compound and on CSB test trials outside the compound have indicated that there may be a deficit in transfer from inside to outside the compound which is consistent with generalisation decrement hypotheses. In particular, Seger and Scheuer (1977), using a conditioned suppression procedure, found that CSB produced even more suppression of responding than CSA within the CSA-CSB sequence (cf. Brahlek, 1968; Scheuer & Keeter, 1969). When CSB was presented outside the compound, CSB produced less suppression than CSA. Similarly, Kehoe (1979), using the rabbit NMR, and Bond (1982), using taste aversion learning in rats, found a high level of responding during CSB inside the serial compound which approximated that of the single-stimulus control while the level of responding to the same CSB outside the compound was generally low. However, these two latter investigations also found evidence which suggests that the level of responding during CSB inside the serial compound may be a contaminated index of CSB's associative strength since CSA by itself was found to have residual response-evoking characteristics during the interval occupied by CSB. Thus, the level of responding during CSB inside a serial compound may represent the summation of the separate response-evoking capabilities of CSB and the latter portions of CSA (Bond, 1982; Kehoe, 1979).

CSA-CSB Relation

Analytic Studies

Recent studies of serial compound conditioning have attempted to delineate the role of the CSA-CSB sequence in facilitating response acquisition to CSA. Indirect evidence that the CSA-CSB sequence is necessary for facilitation has been found in repeated observations that responding to CSA in a serial compound exceeds the level obtained in an "uncoupled" condition containing interspersed CSA-US and CSB-US trials but lacking the CSA-CSB sequence. This difference has been found on a between-subjects basis in the rabbit NMR (Gibbs, 1979; Kehoe et al., 1979, Experiment 3), food-reinforced "head jerk" in rats (Holland & Ross, 1981, Experiment 1), conditioned suppression of barpressing by rats (Pearce et al., 1981, Experiment 3), and conditioned suppression of licking (Pearce et al., 1981, Experiment 5).

Other investigations have attempted to ascertain the contribution of the CSA-CSB relation by interspersing CSA-CSB trials with CSB-US trials (Gormezano & Kehoe, in press; Rescorla, 1982, Experiment 4). Specifically, Gormezano and Kehoe (in press) compared the levels of rabbit NMR conditioning to CSA in three groups. A serial compound group (SC) received 30 CSA-CSB-US trials per session, and a second-order conditioning group (PP) received 30 CSA-CSB trials intermixed with 30 CSB-US trials. To ascertain whether differences between Groups SC and PP might arise from the deleterious effects of the 50% partial reinforcement schedule in effect for CSB in Group PP, another serial compound group (PR) was created by interspersing the 30 CSA-CSB-US trials with 30 CSA-CSB trials per session. Thus, group PR had a 50% partial reinforcement schedule for CSB but also had twice as many CSA-CSB pairings as either Group SC or PP. In all three groups, the CSA-CSB interval was 1,400 msec, and the CSB-US interval was 400 msec. The study also included unpaired nonassociative control groups (UP, PU, and UU) for Group PP (cf. Rizley & Rescorla, 1972). Observation of the level of responding to CSA revealed that both serial compound groups (SC and PR) showed CR acquisition to CSA which reached a

mean level around 45% CRs at the termination of training. Their level of responding to CSA was significantly higher than that of the second-order conditioning group (PP), which showed a terminal level of responding around 25% CRs. The nonassociative controls showed virtually no responding to CSA. Thus, there was reliable second-order conditioning, which however appeared to be only partially responsible for acquisition to CSA in the serial compound groups. The differences in the levels of responding to CSA were not an artifact of the levels of responding to CSB. Examination of responding to CSB revealed that Groups, SC, PR, PP, and UP (a cross-modal generalisation control) all showed a uniform rate of CR acquisition which reached a mean level of 70% CRs at the termination of the experiment.

Rescorla (1982, Experiment 4) used a within-subjects design to determine whether responding to CSA in a serial compound represents the joint contributions of the CSA-CSB, CSA-US, and CSB-US relations. Pigeons received autoshaping of their keypeck with four different kinds of interspersed trials: (1) a reinforced serial compound (CSA-CSB-US), (2) a trace conditioning trial (CSC-US), (3) a second-order conditioning trial (CSC-CSB), and (4) a CSA-alone trial to equate the number of CSA exposures to that of CSC. All the stimuli were 5-sec presentations of distinctive keylights (i.e., green, yellow, and white). If responding in a serial compound resulted from the cumulative contribution of direct conditioning of CSA, associative transfer from CSA-CSB pairings, and transfer from CSB-US pairings, then responding to CSC would be expected to be as high as that of CSA. In fact, the rate of pecking to CSC showed no increase across training while pecking to CSA in the serial compound showed substantial increases. Consequently, Rescorla (1982) advocated a perceptual-style hypothesis contending that CSB acted as a "catalyst" for a direct association between CSA and the US.

To further show that an intervening stimulus can strengthen a remote association between two events, Rescorla (1982, Experiment 5) examined second-order autoshaping under two conditions: one in which a distinctive stimulus filled a gap between the CS2 and the CS1, and one in which the gap was left empty. In order to reveal the strength of the CS2-CS1 association, Rescorla then extinguished responding to one of the first-order CSs. Unfortunately, the logic of Rescorla's within-subjects design dictated that the alternate CS1 be reinforced so that there was no conventional, unmanipulated condition against which to compare the effects of CS1 extinction. In accordance with Rescorla's expectations, it was found that responding to the CS2 which had been followed by a filled gap prior to CS1 showed a decline in responding while the CS2 which had been followed by an unfilled gap did not show a decline after CS1 extinction.

CSA-CSB Interval

Wickens and his associates were the first to conduct systematic studies of serial compound conditioning using the human galvanic skin response (Wickens, 1959; Wickens, Gehman & Sullivans, 1959), the cat galvanic skin response (Wickens, Born & Wickens, 1963; Wickens, Nield, Tuber & Wickens, 1973), and the cat paw flexion response (Wickens et al., 1973). In all these experiments an overlapping compound of tone and light was used. The CSB-US interval was fixed at 500msec, and the CSA-CSB interval was manipulated over values ranging from 135 to 2,000 msec, thus also varying the CSA-US interval. Following reinforced training with the compound, CSA and CSB were tested in extinction. Although the CSB-US interval was constant, responding to CSB during extinction testing varied as a U-shaped function of the CSA-CSB interval. The minimum of the function was obtained when the CSA-CSB interval was 500 msec, at which point the level of responding on CSB test trials was lower than that on CSA test trials. In a complementary fashion, responding to CSA was an inverted U-shaped function of the CSA-CSB interval with its maximum at 500

msec. Responding to CSA was lower than responding to CSB at the tails of the function. Subsequently, Wickens et al. (1959, 1963, 1973) concluded that the reversal in the relative levels of responding to CSA and CSB at the 500-msec CSA-CSB interval represented a facilitation of responding to CSA and a deficit in responding to CSB on test trials. In addition, Wickens et al. (1973) may have observed some facilitation of CR acquisition at the longer CSA-US intervals; Wickens et al. mention that, early in serial compound training, cats responded during the isolated portion of CSA antedating CSB. Since none of Wickens' studies included single-CS controls, their outcomes can only be regarded as suggestive of positive and negative interactions.

Subsequent studies have confirmed that the CSA-CSB interval can affect positive and negative interactions in serial compounds but these studies have failed to support Wickens' specific conclusions regarding the parametric values governing positive and negative interactions. Investigations of the CSA-CSB interval which have included single-stimulus controls have been reported by Baker (1968), Kehoe et al. (1979) and Kehoe (1976, 1979). Specifically, Baker (1968) describes an unpublished experiment by Schoeninger who examined the effects of CSA-CSB intervals in an overlapping compound using a rabbit avoidance procedure. The level of responding to CSA in extinction was an inverted-U shaped function of the CSA-CSB interval similar to that found by Wickens (cf. Baker & Schoeninger, 1969). Nevertheless, in comparison to the single-CS controls, there was evidence of impairment rather than facilitation because responding to CSA at all intervals fell below that of corresponding single CS controls. No data were reported for responding to CSB.

In Kehoe et al. (1979, Experiment 1), the CSB-US interval was fixed at 350 msec and the CSA-CSB interval was varied across values of 400, 900, 1,400 and 2,400 msec Unlike Wickens' overlapping compound, the duration of CSA was held constant at 400 msec, thus producing sequential compounds with "empty" trace intervals of 0, 500, 1,000, and 2,000 msec between the offset of CSA and onset of CSB. The pattern of responding on CSB test trials agreed with that found by Wickens and his associates. Under the 400-msec CSA-CSB interval responding to CSB showed a low level of responding, which in fact fell below the level of responding to the less contiguous CSA. At longer CSA-CSB intervals the level of responding on CSB test trials progressively increased and exceeded the level of responding to CSA. In a second experiment, Kehoe et al. (1979) replicated the sequential compounds with the 400 and 2,400-msec CSA-CSB intervals and included single-stimulus controls. Under the 400-msec CSA-CSB interval the level of responding on CSB test trials fell significantly below the high level of responding seen in the corresponding single CS control, thus providing an unequivocal demonstration of a negative interaction. At the 2,400-msec CSA-CSB interval the level of responding on CSB test trials was high and failed to differ from that of the corresponding single-stimulus control. While Kehoe et al.'s results for CSB conformed to those of Wickens, examination of responding to CSA failed to show the expected facilitation at the 400-msec CSA-CSB interval. In fact, there was a slight, but *significant negative interaction. Conversely, the longer 2,400-msec CSA-CSB interval* yielded a massive, initial facilitation of responding to CSA when compared to a single CS control. Moreover, this facilitation of CR acquisition to CSA appeared to extend *out to CSA-CSB intervals of 4,000, 8,000 and 18,000 msec (Experiment 4).*

While Wickens et al. (1959, 1963, 1973) and Kehoe et al. (1979) found a low level of responding to CSB only when the CSA-CSB interval was short (400-500 msec), Kehoe (1979) observed a uniformly low level of responding on CSB test trials across a wide range of CSA-CSB intervals stretching from 200 to 1,600 msec. Responding to CSA was constant across the same CSA-CSB intervals (Kehoe, 1976, 1979). However, Kehoe (1979) manipulated the CSA duration so that CSA filled the entire CSA-CSB interval and terminated at the time of CSB's onset. Accordingly, any stimulus

properties of CSA offset always coincided with CSB onset regardless of variations in the CSA-CSB interval. Evidence for the stimulus properties of CSA offset were found by examining the distribution and likelihood of responses on CSA test trials. In particular, the distributions of response latencies tended to be bimodal showing one peak after CSA onset and a second peak after CSA offset (Kehoe, 1976). Furthermore, a percentage CR measure of responses following CSA offset was inversely related to the interval between CSA offset and US onset in a manner identical to that expected from standard manipulations of the CS-US interval.

The foregoing studies all fixed the CSB-US interval and covaried the CSA-CSB and CSA-US intervals. More recent studies have fixed the CSA-US interval and have allowed the CSA-CSB and CSB-US intervals to vary in a reciprocal fashion. Specifically, Pearce et al. (1981, Experiment 4) and Rescorla (1982, Experiment 1) carried out comparable manipulations in conditioned suppression of licking and autoshaping of keypecking, respectively. In both cases there were three sequential compound conditions: (1) one in which the entire gap between CSA-offset and the US was filled by CSB, (2) one in which the first half of the gap was filled, and (3) one in which the latter half was filled by CSB. In both studies the serial compound with the completely filled gap produced the highest level of responding to CSA which was slightly greater than that produced by the compound with the first portion of the gap filled with CSB. Both of these serial compound conditions produced greater levels of responding to CSA than a CSA trace conditioning procedure. In Pearce et al.'s study the serial compound with the CSB in the latter half produced little acquisition of suppression which in fact was lower than that of the CSA trace conditioning control. In Rescorla's study the comparable compound produced a level of responding which was only marginally greater than that of the CSA trace conditioning control. Since both sets of investigators reported that the pattern of response acquisition to CSB inside the compound was identical across conditions, the differences in the level of responding to CSA across the serial compounds appeared to arise from the differences in the temporal relation between CSA and CSB rather than the CSB-US relation.

Comparison with second-order conditioning. There is no self-contained experiment which directly compares the effects of the CSA-CSB interval in serial compound conditioning to the effects of the CS2-CS1 interval in a second-order conditioning procedure. However, Cool (see Gormezano & Kehoe, 1981, pp. 20-21) and Kehoe et al. (1981a, Experiment 2) have examined acquisition of the rabbit's NMR as a function of the CS2-CS1 interval under conditions which duplicated those of serial compound conditioning studies conducted in the same laboratories. In serial compound conditioning, manipulations of the CSA-CSB interval over the range 400 to 2,400 msec yielded a uniformly rapid rate of CR acquisition to CSA (Kehoe et al., 1979). To determine whether the same was true for second-order conditioning, examinations of the CS2-CS1 interval were undertaken. Both second-order conditioning studies followed the same procedures with minor differences. Each day of training consisted of 30 CS1-US first-order trials interspersed with 30 CS2-CS1 second-order trials. The CS1-US interval was 400 msec. In Cool's study, separate groups received CS2-CS1 intervals ranging between 400 and 8,400 msec while Kehoe et al. used values between 400 and 2,400 msec. In order to control for cross-modal generalisation from CS1 and CS2, both studies included a group which received 30 unpaired presentations of CS2 and CS1 interspersed among the CS1-US trials. Both studies revealed that the level of CR acquisition to CS2 was not uniform across CS2-CS1 intervals but rather displayed a steep "contiguity gradient" which paralleled the gradients produced by CS-US interval manipulations. At CS2-CS1 intervals of 2,400 msec and greater, the level of responding to CS2 was only slightly higher than in the generalisation control condition. It appears then that the high levels of responding to CSA at long CSA-CSB intervals cannot be easily attributed to second-order conditioning between CSA and CSB in a serial compound.

Comparison between simultaneous and serial compounds. The range of manipulation in the CSA-CSB interval has not usually included the zero value necessary to produce a simultaneous compound. However, Kaplan and Hearst (1982, Experiment 4) have recently compared the effects of simultaneous and serial compounds on acquisition of approach to a keylight in pigeons at long trace conditioning intervals. They used a 12-sec keylight CSA followed by a 12-sec interval and 3-sec access to grain. CSB onset was the termination of a tone which otherwise was present during food access and the intertrial interval. In one group, the presentation of CSB overlapped the entirety of CSA and the interval, thus producing a CSA-CSB interval of zero. A second group had a CSA-CSB interval of 6 sec, and a third group had a CSA-CSB interval of 12 sec. Thus, the interval between CSA and the US was always filled by CSB and the compound groups differed only in the overlap between CSA and CSB. A fourth group acted as a CSA trace conditioning control which received the 12 sec CSA plus a simultaneous 12-sec presentation of the tone which was otherwise off. During training, the 12-sec CSA-CSB interval produced the highest level of approach to the key, the 6-sec CSA-CSB interval produced a modest level of approach to the key, and the 0-sec CSA-CSB interval produced no acquisition of approach behaviour, nor did the trace control group. Thus, the serial presentation of CSA and CSB onsets appeared necessary to facilitate the acquisition of responding at long CSA-US intervals.

Kehoe (in press) has compared the effects of simultaneous and serial compounds on responding to CSB. CSA was a highly salient, 800-msec tone CSA which was fixed at an 800-msec CSA-US interval and CSB was either an 800, 600, or 400-msec, light CSB. Thus, the former compound was a simultaneous compound while the latter two compounds were serial compounds. In the simultaneous compound, the intense CSA would be expected to overshadow CSB. For the serial compounds, the information hypothesis would expect the temporal primacy of CSA to cause additional impairments in CR acquisition to CSB (Cantor & Wilson, 1981; Egger & Miller, 1962). The reverse occurred. Interspersed tests with CSB revealed that the level of responding to CSB in the serial compound groups showed less impairment than did responding to CSB in the simultaneous compound group. Thus, CSB's greater contiguity with the US in the serial compounds counteracted the deleterious effect of CSA's salience even when CSA also had temporal primacy. Finally, there was a tendency for the level of responding to CSA to parallel the level of resonding to CSB but the effects on responding to CSA were small in absolute terms and did not suggest either a pronounced facilitation or impairment.

CSA-CSB Similarity

Levis and his associates have extensively examined stimulus generalisation of a presumed fear CR within compounds which signal aversive USs (Levis, 1966; Levis & Stampfl, 1972). As one means for varying the similarity between the early and later segments of a compound consisting of auditory and visual components, Levis and his associates have manipulated the number of common stimulus elements in the successive portions of a compound CS. To depict the common elements, Levis represented a simultaneous compound as S1S2/S1S2 and a single CS as S1/S1, where the slash mark indicates the midpoint of the total CS-US interval. Thus, in a simultaneous compound, the first and second halves of the CS-US interval possess both components in common. Under Levis' scheme, an overlapping compound (S1/S1S2) has one element in common between its two segments, and the sequential compound (S1/S2) has no elements in common across its segments. Hence, as the similarity among a compound's successive segments decreases, the generalisation of a fear CR would decrease and the latency of an avoidance response would increasingly fall in the second segment of the compound. In accord with this generalisation

hypothesis, two-way shuttle avoidance responses showed a shorter latency under a simultaneous compound or single-CS than under overlapping or sequential serial compounds of comparable durations (Levis, 1970; Levis & Boyd, 1973; Levis & Dubin, 1973; Levis & Stampfl, 1972). An even greater delay was obtained in a serial compound in which the total CS-US interval was partitioned into three segments (Levis, 1970). In further agreement with the generalisation hypothesis, Levis observed that the overlapping compound tended to produce slightly more responding to the first component than did the sequential compound (Levis & Boyd, 1973; Levis & Dubin, 1973).

To further test the generalisation hypothesis, Dubin and Levis (1973) manipulated the physical similarity between CSA and CSB of a sequential compound in both two-way avoidance and conditioned suppression procedures. In both investigations, there were eight groups: four groups received a 4-kHz tone as CSB and the other four groups received a 13.5-kHz tone as CSB. Within each set of four groups, the CSA was either 4, 6, 9, or 13.5 kHz, respectively. As predicted by the generalisation hypothesis, the level of responding to CSA increased as the physical similarity between CSA and CSB increased. The results obtained in the conditioned suppression procedure were particularly dramatic. The groups trained with identical tone components showed nearly total suppression to CSA, while the groups trained with the greatest difference between the tone components showed a level of suppression to CSA that did not differ from that produced by unpaired controls.

Levis' findings seem to indicate that mechanisms tied to the physical similarity between components of a serial compound can play a major role in the transfer of responses from more contiguous elements of a serial compound to temporally remote elements. However, it remains to be determined whether the delay in responding seen with increasing differentiation of the total stimulus duration represents not only a failure of generalisation but also the development of an active inhibition during the early segments of the total stimulus. Levis' studies all found that the delay of responding in serial compounds appeared from the beginning of training, a result more suggestive of a failure of generalisation from CSB to CSA than an acquired inhibition of responding to CSA. Some support for the eventual acquisition of differential inhibition within a serial compound was shown in that response latency gradually increased over sessions and the likelihood of responding during the first component concomitantly decreased (Levis & Boyd, 1973; Levis & Dubin, 1973; Levis et al., 1978, Experiment 2).

Holland and Ross (1981, Experiment 3) have recently examined the effects of physical similarity on facilitation of response acquisition to CSA in appetitive conditioning of the rat. Specifically, they compared acquisition of the head jerk response in two groups both of which received intermixed training with two visual-auditory sequential compounds. For one group, both compounds had components with similar temporal patterns where one compound consisted of an intermittent panel light followed by an intermittent white noise and the other compound consisted of continuous houselight followed by continuous tone. In the second group, the two compounds had dissimilar components, i.e., the intermittent panel light was followed by the continuous tone, and the continuous light was followed by the intermittent noise. All compounds were followed by food presentation. The group trained with compounds of the similar components showed a higher level of responding to CSA during acquisition than that of the group trained with compounds of dissimilar components. Since both groups received equal training with both the intermittent and continuous auditory CSBs, the opportunity for stimulus generalisation from both CSBs to both CSAs would be equal, both across and within compounds. Consequently, Holland and Ross (1981) argued that similarity between CSA and CSB within a compound also aids second-order conditioning (cf. Rescorla & Furrow, 1977).

GENERAL DISCUSSION

The body of data from serial compound conditioning studies reveals that even the simplest compound composed of merely two components can produce profound interactions among the components. In general, response acquisition to CSB appears to suffer impairments, at least when CSB is tested outside the context of the serial compound. However, there is emerging evidence that, inside the context of the compound, CSB and its relation with the US may exert a greater impact on response acquisition than the test trial results would suggest. With regards to CSA, the picture is even more complicated. Response acquisition to CSA has been subject to both substantial facilitation and substantial impairment. Moreover, some impairments in acquisition to CSA appear early in training, after as little as one serial compound training trial (e.g., Mackintosh & Reese, 1979; Revusky, 1971), and other impairments appear in the form of reductions in the level of responding to CSA after initial acquisition of responding to CSA (e.g., Brahlek, 1968; Kehoe et al., 1979, 1981a).

Despite the diversity of outcomes, it is possible to systematise them according to the relative effectiveness of the CSA-US and CSB-US intervals. It is possible to divide the range of CS-US interval effects into three zones. The outer zone includes those CS-US intervals which produce little or no response acquisition regardless of whether a trace or delay conditioning procedure is used. The intermediate zone includes those CS-US intervals which by themselves produce modest rates of conditioning; this zone includes those intervals in which delay procedures yield substantially higher rates of response acquisition than trace procedures. The inner zone includes those CS-US intervals which reliably produce high rates of acquisition regardless of whether trace or delay procedures are used. In most studies of serial compound conditioning, the CSB-US interval has fallen in the inner zone while CSA-US intervals have ranged through all three zones. Facilitation of response acquisition to CSA has generally occurred when the CSA-US intervals fall in the outer or intermediate zone, while impairments in initial response acquisition to CSA have occurred most reliably when the CSA-US interval has fallen in or near the inner zone. Finally, impairments in response acquisition to CSB also appear to require that the CSA-US interval is in or near the inner zone. For example, in conditioning of the rabbit NMR, the entire range of CSA-US intervals has been explored and the pattern of results generally conforms to the proposed scheme. For outer CSA-US intervals, substantial facilitation of CR acquisition to CSA has been obtained while no impairment in response acquisition to CSB has been observed (Kehoe et al., 1979, 1981a). At intermediate and inner CSA-US intervals, small impairments in CR acquisition to CSA have been obtained but substantial impairments in acquisition to CSB have been consistently obtained (Kehoe, 1979; in press; Kehoe et al., 1979). Research with other preparations has not explored the CSA-US temporal relation so extensively but the pattern of results across studies is consistent with the proposed scheme. The relation between the effectiveness of the CSA-US interval and level of acquisition to CSA can be seen by comparing the outcomes of two studies of lick suppression in rats (Mackintosh & Reese, 1979, Experiment 2; Pearce et al., 1981, Experiment 4). On the one hand, Pearce et al. (1981) obtained facilitation of acquisition to CSA when using a 30-sec CSA and a 60-sec CSA-US interval which by themselves produced a moderate rate of acquisition over the course of four conditioning trials. On the other hand, Mackintosh and Reese (1979) found an impairment in acquisition to CSA when using a 15-sec CSA and 45-sec CSA-US interval which by themselves yielded nearly complete suppression after a single conditioning trial. Elsewhere, facilitation of response acquisition to CSA has appeared in a variety of appetitive preparations (Holland & Ross, 1981; Kaplan & Hearst, 1982; Rescorla, 1982) using CSA-US trace intervals which by themselves yielded little discernible response acquisition. Similarly, moderate facilitation has appeared in conditioned suppression of barpressing in which CSA trace conditioning yielded little suppression but CSA delay conditioning yielded substantial suppression

(Bolles et al., 1978; Kamin, 1965; Pearce et al., 1981). Finally, consistent impairments in response acquisition to CSA and CSB have been observed in taste aversion learning procedures which have the widest inner zone of all conventional conditioning procedures (e.g. Bond, in press; Revusky, 1971; Kalat & Rozin, 1971).

The foregoing scheme is intended strictly as an empirical generalisation providing a testable rule of thumb for predicting when initial facilitation or impairment will occur in serial compound conditioning. By the same token, the scheme does not specify the mechanism governing any of the effects of serial compound conditioning. However, as was noted in the Introduction, the results of serial compound conditioning seem particularly relevant to the wider theoretical issues of "remote associations" and "stimulus selection". First, facilitation of acquisition to CSA and subsequent reductions in responding to CSA appear to be most pertinent to identifying mechanisms capable of facilitating response acquisition to stimuli which are temporally remote from the reinforcer. Second, the impairments in the initial acquisition to CSA and CSB appear most pertinent to identifying mechanisms underlying "stimulus selection" effects.

Remote Associations

One of the more dramatic outcomes of serial compound conditioning has been the facilitation of response acquisition to CSA at long, otherwise ineffective CSA-US intervals (Bolles et al., 1978; Kamin, 1965; Kehoe et al., 1979, 1981a; Kaplan & Hearst, 1982; Pearce et al., 1981; Rescorla, 1982). Attempts to identify the key mechanisms have been only partially successful. At present, it appears that the total level of responding arises from small but cumulative contributions from a variety of mechanisms. The possible contributors can be divided into two classes: (1) nonserial factors which operate even without actual presentation of the CSA-CSB sequence and (2) serial factors which depend on presentations of the CSA-CSB sequence or the entire serial compound, CSA-CSB-US.

Among the nonserial factors, stimulus generalisation from CSB to CSA can be a highly potent factor in producing responding to CSA (e.g., Dubin & Levis, 1973). However, stimulus generalisation does not appear to be a necessary factor because substantial facilitation has been obtained even when stimulus generalisation has been demonstrably minimised by the use of CSs from different modalities. The possibility of general transfer from CSB-US training to CSA-US training, i.e., learning-to-learn, has not been separately evaluated, but training with interspersed CSA-US trials and CSB-US trials has consistently produced less responding to CSA than serial compound training (Holland & Ross, 1981; Kehoe et al., 1979; Pearce et al., 1981; Rescorla, 1982). In summary, the joint contributions of nonserial factors can be substantial but do not completely account for response acquisition to CSA in many cases.

Among the serial factors, the most obvious candidate has been associative transfer mechanisms as defined in studies of second-order conditioning and sensory preconditioning. However, associative transfer mechanisms may play only a limited role in promoting response acquisition to CSA in a serial compound. The evidence that weighs most heavily against associative transfer mechanisms includes the following: (1) Kehoe et al. (1979) demonstrated that, in the rabbit NMR preparation, facilitation of CR acquisition to CSA in a serial compound would occur at CSA-CSB intervals ranging up to 2,400 msec and perhaps longer. However, second-order conditioning in the same preparation is at best very weak at CS2-CS1 intervals of 2,400 msec. Even under optimal conditions, the level of second-order conditioning falls short of the levels of responding to CSA in serial compounds (Gormezano & Kehoe, 1981; Kehoe et al., 1981a); (2) Rescorla (1982, Experiment 4) found that, in

autoshaping of the pigeon's keypeck, serial compound conditioning produced a higher level of responding to CSA than a comparable CS which was subject not only to second-order conditioning but also the contribution of nonserial factors. However, the failure of second-order conditioning to account fully for responding to CSA in a serial compound may reflect the shortcomings of a purely analytic approach to serial compound conditioning. In particular, the very separation of a serial compound into its constituent pairs of events may engage inhibitory processes which are minimised in serial compound training. For example, in second-order conditioning, the unreinforced CS2-CS1 presentations rapidly produce declines in responding to CS2 after initial acquisition to CS2 (e.g., Herendeen & Anderson, 1968; Kehoe et al., 1981a). In addition to the possibility that estimates of second-order conditioning and perhaps nonserial processes are too low, it may be that the various contributors combine in a synergistic rather than independent fashion. In summary, the exact magnitude of the contribution by associative transfer and nonserial factors to serial compound conditioning will remain uncertain, at least until a sound quantitative model is developed.

Beyond the processes subject to separate analysis, there is growing evidence of serial processes which depend on the integrity of the entire reinforced serial compound. The simplest of this class of hypotheses has been inspired by Mowrer & Lamoreaux's (1951) explanation for the inferiority of trace conditioning relative to delay conditioning (Kaplan & Hearst, 1982). According to this hypothesis, the interval between CS and US in trace conditioning is identical to the intertrial interval. Thus, *the conditioning trial as a whole is poorly differentiated from the prevailing* background stimuli and any event which fills the trace interval will more clearly differentiate the CS and its traces from the background stimuli. Although Mowrer and Lamoreaux's hypothesis is not clear as to the exact influence of the intervening stimulus event, it does suggest that CSB in a serial compound may facilitate direct CSA-US conditioning. Other investigators have also entertained the possibility that CSB acts in some unspecified way as a catalyst for direct CSA-US conditioning (Kehoe et al., 1981a; Rescorla, 1982).

Evidence for facilitation of direct CSA-US conditioning is less than persuasive. Kaplan and Hearst (1982) along with others (Pearce et al., 1981; Rescorla, 1982) found that filling the entire interval between CSA and the US produced higher levels of responding to CSA than filling only a portion of the gap. However, Kaplan and Hearst (1982) found that even when the entire interval was filled by CSB, responding to CSA was dramatically affected by the degree of overlap between CSA and CSB. More specifically, acquisition of responding to CSA depended on the serial relation between CSA and CSB onsets. If CSA and CSB had simultaneous onsets there was no acquisition to CSB even though the conditioning trial was well differentiated from the background stimuli. Conversely, it has been possible to obtain substantial facilitation of acquisition to CSA when only a small fraction of the trace interval is filled. Specifically, in the rabbit NMR preparation, acquisition to CSA has been repeatedly obtained when CSB fills only the last 400 msec or less of a 2,400-msec trace interval (Kehoe et al., 1979, 1981a). These experiments showed that the level of responding to CSA depended on the effectiveness of the CSB-US interval (Kehoe et al., 1981a). Recently, Rescorla (1982, Experiment 5) attempted to demonstrate that a filler stimulus would enhance the strength of a direct association between two events, namely CS2 and CS1 in a second-order conditioning paradigm. He found that a filler stimulus between CS2 and CS1 made the level of responding to CS2 more susceptible to the deleterious effects of CS1 extinction. However, it does not appear that Rescorla (1982) could have prevented the filler stimulus from becoming an intermediate link in a CS2-filler-CS1 association rather than just a catalyst to the CS2-CS1 association. If there are facilitative processes unique to the serial compound, they would appear to be

governed by many of the same variables that govern associative transfer, viz., CSA-CSB relation and CSB-US relation.

Stimulus Selection

The major findings from serial compound conditioning studies which bear on contemporary accounts of stimulus selections effects are as follows:

(1) Response acquisition to CSA can be impaired by serial compound training alone (e.g., Bond, in press; Mackintosh & Reese, 1979; Revusky, 1971) or in conjunction with prior training of CSB (Cheatle & Rudy, 1978; Gibbs, 1979; Pearce et al., 1981; Revusky, 1971);

(2) Response acquisition to CSB as measured on test trials can be impaired by serial compound training alone (Bond, in press; Egger & Miller, 1962; Kehoe, 1979; in press; Kehoe et al., 1979; Revusky, 1971) or in conjunction with prior training of CSA (Gaioni, 1982; Kehoe et al., 1981b);

(3) The relationship between impairments in acquisition to CSA and CSB is not entirely clear but there have been repeated instances in which acquisition to CSB is more impaired than that to CSA (e.g., Egger & Miller, 1962; Kehoe, 1979; in press; Kehoe et al., 1979; Wickens et al., 1959, 1963, 1973);

(4) Even when response acquisition to CSB displays severe impairments when tested by itself, the CSB-US relation appears to have a profound impact on response acquisition to a serial compound and its components. In instances where CS-US interval effects have been well delineated, the CSB-US interval appears to determine the rate and level of response acquisition to the serial compound as a whole and also to CSA (Frey et al., 1971; Kehoe, 1979; in press; Kehoe et al., 1981a);

(5) Measurements of responding inside the compound have revealed that (a) the level of responding during CSB is predictable from the CSB-US interval (Kehoe, 1979), (b) the addition of CSB to form a serial compound can cause a progressive localisation of responding during CSB even though CSA has had prior training (Gaioni, 1982), and (c) the level of responding during CSB inside the context of the serial compound is substantially higher than the level of responding to the same stimulus when tested by itself (Bond, 1982; Gaioni, 1982; Kehoe, 1979; Seger & Scheuer, 1977).

Generalisation Decrement Hypotheses

Among the available accounts of stimulus selection effects, perceptual accounts such as the generalistion decrement hypotheses have been frequently offered to explain serial compound conditioning (e.g., Borgealt et al., 1972; Hancock, 1982; Rescorla, 1972b; Wickens, 1959, 1965, 1973). Since generalisation decrement hypotheses assume that all stimuli in a compound have undiminished access to the associative apparatus, then it would be expected that the CSB-US interval and CSB intensity would determine the rate of response acquisition to a compound (Frey et al., 1971; Kehoe 1979; in press). Likewise, the ordered effects of the CSB-US interval and CSB intensity on the level of responding to CSB on test trials would presumably reflect the differences in CSB's associative strength gained inside the compound (Kehoe, in press). Nevertheless, the relatively low level of responding on CSB test trials would be expected because of the disparity between the encoding of CSB inside the context of the compound and the encoding of CSB on test trials outside the compound. While a deficit in transfer from compound conditioning to testing with CSB can explain the low level of responding to CSB on test trials, any impairments in responding to CSA cannot be attributed to a similar deficit in transfer because the encoding of the initial portion of CSA is only affected by static background stimuli which are the same

whether or not CSB is subsequently presented (e.g., Borgealt et al., 1972; Hancock 1982). However, James and Wagner (1980) have recently offered a generalisation decrement hypothesis suitable for explaining impairments in response acquisition to CSA in a serial compound. Following Hull's (1943) account of response acquisition, James and Wagner contend that responding to the initial portion of CSA depends on generalisation of associative strength from the encoding of CSA at the time of US occurrence (cf. Gormezano, 1972; Gormezano & Kehoe, 1981, p. 15). Consequently, the encoding of CSA may be altered by the occurrence of CSB just before US presentation which would tend to reduce the generalisation of associative strength from the point of reinforcement to the earlier portions of CSA.

From the perspective of generalisation decrement hypotheses, the results of blocking manipulations in serial compounds have become more intriguing as they have accumulated. On the one hand, blocking has been considered a substantial stumbling block to generalisation decrement accounts, because the routine control procedures demonstrate that the low level of responding to the added CS cannot be attributed entirely to generalisation decrement from compound training to component testing (Kehoe et al., 1981b; Marchant & Moore, 1973). Yet, Gaioni's (1982) results suggest that, inside the context of a serial compound, CSB can acquire substantial associative strength even when CSA has received prior training. What is more startling is that the addition of CSB can actually reduce the established level of responding to CSA (cf. Brodigan & Trapold, 1974; Levis et al., 1978). If Gaioni's results can be confirmed, then a compelling theoretical question remains: How does the pretraining of a CS lead to a greater alteration in the encoding of the added CS? A similar problem for generalisation decrement theories arises in connection with demonstrations that prior training of CSB can partially block acquisition to CSA. It would be possible to appeal to James and Wagner's hypothesis of within-compound generalisation decrements to account for the impairment in response acquisition to CSA. However, the extension of James and Wagner's (1980) hypothesis to blocking of CSA still leaves the mechanism of encoding unspecified.

Selective Attention Theory

As a plausible alternative to a generalisation decrement hypothesis, a selective attention hypothesis would contend that the onset of CSA would fully engage the subject's attention but with the passage of time, attention to CSA would wane (Kehoe, 1979). Accordingly, response acquisition to CSB would be most hindered if CSB were to have an onset simultaneous with CSA (Kehoe, in press). However, if the CSB onset were delayed, more attentional capacity would become available for CSB thus enabling increased levels of response acquisition to CSB. Since CSB would take up unused attentional capacity, the temporal and intensive characteristics of CSB would make a substantial contribution to overall response acquisition as was observed in the effects of the CSB-US interval and CSB intensity on response acquisition to serial compounds (Kehoe, 1979; in press). Similarly, the level of responding during CSB inside the serial compound would be attributed to summation of the separate response tendencies to CSB and the later portions of CSA or its traces (Bond, 1982; Kehoe, 1979). Although CSB is able to take advantage of any currently unused attentional capacity, it could also detract from the previously established attention to CSA. This would lead to impairment of response acquisition to CSA (Mackintosh & Reese, 1979).

An account of blocking within a serial compound also follows from a selective attention theory. Selective attention theory can also account for what may be an asymmetry in the degree of blocking possible for CSA and CSB. Specifically, it has been possible to obtain nearly complete blocking of CSB through prior training of CSA. However, complete blocking of CSA through prior training of CSB has never

been observed (cf. Kehoe et al., 1981b, Experiment 3). Under a selective attention theory, the difficulties encountered in blocking CSA would be attributed to the fact that the temporal primacy of CSA would allow it to engage the animal's attention before the onset of CSB thus offsetting the advantage accrued to CSB through previous training. Conversely, in blocking of CSB, the primacy of CSA and the prior training of CSA would act in concert to preclude attention to CSB. However, demonstrations that the addition of CSB can detract from previously established responding to CSA seriously challenge current selective attention hypotheses (Brodigan & Trapold, 1978; Gaioni, 1982; Levis et al., 1978).

Other *Competition Hypotheses*

As alternatives to the selective attention hypotheses, the other competition hypotheses (e.g., Mackintosh, 1975; Pearce & Hall, 1980; Rescorla & Wagner, 1972) are difficult to extend to serial stimulus selection effects. While these hypotheses have detailed trade-off processes which attenuate the associative effects of CS-US contiguity, they only deal with "CS-US contiguity" globally and do not address explicitly the effects of varied CS-US contiguity on conditioning. However, these models do contain a growth parameter which is a function of CS intensity. In order to accomodate the precise effects of the CSB-US interval manipulations it would be possible to assign growth parameters on the basis of the CS-US interval as well as CS intensity. Even using this tactic the associative trade-off models would not be able to account for serial stimulus selection effects given that responding to CSA in the serial compound is frequently higher than responding to CSB. Accordingly, it would be necessary to find some basis for assigning a higher growth parameter to the longer CSA-US interval than to the shorter CSB-US interval. The most obvious source for independent estimates of growth parameters would be data collected from single-CS manipulations of the CS-US interval. However, the rabbit NMR data clearly demonstrate that shorter CS-US intervals produce higher rates of response acquisition than longer CS-US intervals (e.g., Gormezano, 1972; Kehoe, 1979; in press). Accordingly, the single CS data would lead to the incorrect prediction that CSB ought always to impair response acquisition to CSA in a serial compound with CSB suffering at worst small deficits. It might be possible to appeal to second-order conditioning to explain cases in which responding to CSA shows little deficit. However, a second-order conditioning hypothesis would not appear to be readily applicable to the most troublesome case in which responding to CSA shows little impairment while responding to CSB shows massive impairments. For the second-order conditioning hypothesis to apply it would be necessary that CSB possess substantial associative strength if CSB is to serve as a source of reinforcement for response acquisition to CSA.

Information Hypotheses

Although Egger and Miller's (1962) information hypothesis was one of the earliest explanations of the serial stimulus selection effect, it would appear to have great difficulty in encompassing the current body of data concerning serial compound conditioning. Most notably, a simple information hypothesis would expect that the temporally predictive value of CSA for the CSB or the US in a serial compound to impair response acquisition to CSB. Instead, Kehoe (in press, Experiments 1 & 2) observed that there was a higher level of responding to CSB after serial compound training than after simultaneous compound training. Moreover, there have been repeated instances in which the level of responding to CSB, even on test trials, has exceeded the level of responding to CSA (e.g., Baker, 1972; Hancock, 1982; Thomas et al., 1978). It would also appear difficult for the information hypotheses to account for observations that the CSB-US interval and CSB intensity determine the overall level of response acquisition to the compound, CSB, and even CSA.

The most recent version of the information hypothesis has attempted to explain the effects of CS-US interval manipulations in single stimulus situations and the effects of CSA-CSB interval manipulations in serial compound conditioning (Cantor, 1981; Cantor & Wilson, 1981). Nevertheless, this hypothesis incorrectly implies that, if CSA provides maximal information regarding the time of CSB's impending onset, the CSA-US interval ought to determine the rate of CR acquisition. In another attempt to save the information hypothesis, Seger and Scheuer (1977) argue that CSB gains associative strength inside the compound because it provides temporal information about "when shock will occur" but only when CSB is preceded by CSA. Seger and Scheuer's (1977) account uses the language of information hypotheses but it does not assume that a deficit occurs in the acquisition of associative strength to CSB during serial compound training. Instead, their account proposes that there is a deficit in the transfer from serial compound training to the testing of CSB outside the compound. In this respect Seger and Scheuer's account converges with the generalisation decrement accounts which expect a discrepancy between the efficacy of CSB-US contiguity inside a compound and the level of responding to CSB outside the compound (cf. Hancock, 1982; Kehoe, 1979).

Conclusions

The findings from serial compound conditioning indicate that processes of generalisation decrement and/or selective attention play a greater role than previously thought (cf. Kamin, 1969; Rescorla & Wagner, 1972). The feature which distinguishes the generalisation decrement and selective attention hypotheses from the information and associative trade-off hypotheses is the temporal locus of the presumed critical interaction between the two CSs in a compound (James & Wagner, 1980; Mackintosh & Reese, 1979). In generalisation decrement and selective attention hypotheses, the critical interaction between the CSs occurs while the stimuli are being processed prior to the onset of the US. Thus, associative strength will accrue to whichever stimulus encodings are present at the time of the US. However, in the associative trade-off hypotheses, the interaction between two CSs is based on their relative associative strengths at the time of the US occurrence. Prior to US occurrence, the functional representations of the concurrent CSs are assumed to be entirely independent. Mackintosh and Reese (1979) have recently proposed a similar distinction. Their evidence for a pre-US interaction, viz., competition for the animal's attention, involved demonstrations that an overshadowing effect can be obtained through a single pairing of a compound with the US (cf. James & Wagner, 1980). Since neither CS would possess any associative strength on the first trial, the observed overshadowing would have to arise from a direct interaction between the CSs and not from a trade-off based on the accrued associative strengths of the CSs.

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