USE OF ELEMENTAL AND CONFIGURAL CODING IN

TIMING OF COMPOUND STIMULI

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USE OF ELEMENTAL AND CONFIGURAL CODING IN TIMING OF COMPOUND STIMULI

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THESIS ABSTRACT

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The timing of a compound stimulus could provide important information regarding elemental and configural processing. After training with either an elemental (in which the focus was on the individual features of a stimulus array) or a configural (in which the focus was on the entire array) strategy, participants were presented with two cues in compound, each of which individually predicted an outcome at different times.

The pattern of responding across time was different for the group trained to use a configural strategy relative to both the group trained to use an elemental strategy and a control group. The elemental and control groups responded at the time appropriate for one of the cues in the compound. The configural group responded between the temporal expectations of the two cues. Thus, prior experience with either an elemental or a configural strategy influenced how participants responded to a compound. The relevance of this finding to the elemental/configural processing debate is discussed.

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INTRODUCTION

It has long been established experimentally that animals can learn about the temporal properties of stimuli. Pavlov (1928) noted that if an unconditioned stimulus (US) is delivered at a certain time relative to a conditioned stimulus (CS), the conditioned response (CR) intensifies as the time of the delivery of the unconditioned stimulus (US) nears (i.e., the phenomenon of inhibition of delay). Skinner (1938) made a similar observation in an instrumental conditioning preparation. He observed that, if reinforcement occurs contingently on a response given after a regular interval, responding increases in the latter segment of the interval (i.e., the fixed interval scallop). Despite a long history of research in this area, there is still a lack of conceptual agreement regarding some simple features of response timing. For example, two questions which require further investigation are (1) how do animals time events (i.e., what are the underlying mechanisms of timing behavior) and (2) how do animals interpret potentially conflicting information about the time of delivery of an expected outcome? The following sections describe some methods used in the study of response timing, outline two major models of response timing, and briefly describe some theoretical approaches to understanding how animals learn about multiple cues.

Procedures for the Study of Interval Timing

Several experimental procedures reveal a great deal about how animals time the duration of stimuli. The first and simplest is the fixed interval (FI) schedule developed by Skinner (1938). As noted previously, this schedule entails reinforcement for the first response made after a regular interval. After enough experience with the schedule, animals consistently respond more (i.e., at a higher rate or with greater intensity) at the end of the interval than they do at the beginning.

A variation of the FI schedule allows for the measurement of specific temporal expectations. This variation is to introduce *peak trials* into a FI schedule session (Catania, 1970). A peak trial is like any trial within the FI schedule except that reinforcement is not delivered at the elapsed interval and the time to the next reinforcement is significantly longer than the usual interval length. The typical peak trial response function (averaged across trials or subjects) is characterized by an acceleration of responding from the beginning of the trial to the time at which reinforcement is delivered in the FI schedule trials. As the usual reinforcement point passes, responding negatively accelerates (i.e., decelerates). It should be noted that this procedure can be used in both classical and instrumental conditioning experiments. In classical conditioning procedures, responding accelerates as the time of expected US delivery approaches and decelerates as the time of the expected US passes, just as responding accelerates and decelerates around the time of reinforcement in instrumental conditioning (Bitterman, 1964).

Another procedure commonly used in animal timing research is known as *temporal bisection* (Gibbon, 1981). This procedure is essentially a choice procedure. Subjects are trained to make one response if the stimulus is of a set long duration and another response if the same stimulus is of a set short duration. Once criterion is met in training, the duration of the stimulus is systematically altered with values intermediate to the two training durations and subjects' choices of long or short are recorded. The stimulus duration which is as likely to produce a short response as a long response is called the *indifference* or *bisection* point (Gibbon, 1981). This point generally is close to the geometric mean of the two stimulus duration used in training (Gibbon, 1981; Allan & Gibbon, 1991), although some modifications to the basic procedure have resulted in bisection points close to the arithmetic mean, at least with human participants (Allan, 2002).

Psychometric studies of response timing in humans have also used a procedure called *interval production*. In this procedure, human participants are presented with a stimulus of a certain duration. Participants are then asked to respond in such a way as to reproduce the stimulus interval. Wearden (1991) related results from interval production research to results from the peak procedure literature. He found that both procedures reveal similar properties of response timing, such as time-scale invariance (see the following section). The current study will use a variation of interval production procedure because of one of its obvious advantages. In addition to investigating *when* participants respond relative to a CS (as in a peak procedure), interval production allows us to investigate participants' expectation of the *duration* of an outcome stimulus. These two measures of timing will allow us to investigate simultaneously multiple aspects of temporal representation.

Theories of Response Timing

Several theories attempt to explain how animals are able to time responses based on stimulus duration. An early and often cited theory of timing is the *scalar expectancy theory* (Gibbon, 1977; Gibbon, Church, & Meck, 1984). This model posits that there are some processes internal to the animal that account for the ability to learn about stimulus duration. Specifically, these processes include a mechanism that emits pulses (i.e., an internal clock; e.g., Church, 1984), an accumulator that collects emitted pulses, and a memory mechanism that stores memories of durations (number of pulses) that have been reinforced in the past. Other processes important to the model are a switch that determines when the pulse accumulator begins the collection of pulses and a decision process that compares the number of pulses currently stored in the accumulator to representations of previously reinforced number of pulses stored in memory.

According to scalar expectancy theory (SET), the onset of any given trial (the beginning of a CS) causes the switch to close and the accumulator to begin collecting pulses. When another time marking event (i.e., another training trial) occurs, the switch opens again and the number of pulses in the accumulator is compared to a sample of reinforced durations stored in reference memory by means of a ratio of the two numbers. At the beginning of a timed event, the number of pulses in the accumulator is much less than the stored memories for reinforced durations. Only when the number of pulses in the accumulator nears the reinforced number of pulses in memory (i.e., the ratio of the number of pulses in the accumulator to pulses in memory approximates one) does the subject begin to respond.

One main objective of SET is to account for the scalar variability of responding observed in most research on response timing. Scalar variability refers to the relatively constant coefficient of variation in the distribution of the onsets, offsets, and peaks of conditioned responding across different timed event durations (Gibbon, 1977). In other words, the frequency distributions of conditioned responses of different intervals become virtually indistinguishable when the frequency distributions of the intervals are divided by the standard deviation of responding in the interval. SET posits that variability in response timing comes from error in the reading of durations stored in memory rather than from error in timing the duration of the current event (Gallistel, 1999). The error observed in the timing of a CR is said by the model to be proportional to the duration of the event being timed, allowing for the scalar property of variance in response timing.

An alternative explanation of the mechanism underlying timing of an expected event is Killeen and Fetterman's (1988) *behavioral timing theory* (BeT). Instead of relying on a pulse generator and accumulator to record the temporal passage of time, BeT relies on a set of regularly varying behavioral states that a subject experiences within a given trial. The onset of a CS signals the beginning of a behavioral state within the animal. As the CS continues, the first behavioral state gives way to a second, the second to a third, and so on until reinforcement occurs. At the beginning of training, activation (the probability of responses occurring) is spread across each behavioral state equally. As training continues, each behavioral state becomes associated with the CR to varying degrees. The early states (i.e., the states farthest away from reinforcement) have weak associations with the US, and so have a low probability of producing a response. States near the end of the interval have a stronger association with (i.e., are temporally closer to) the US, so responding is highly probable.

BeT accounts for timescale invariance by positing that there is a constant number of behavioral states in any relatively short timed interval (on the order of seconds and minutes), and the spread of activation across behavioral states is proportional to the rate of reinforcement (Killeen & Fetterman, 1988). For instance, a rat could be trained with an inter-stimulus interval of 20 seconds. According to BeT, there are a certain number of states that the rat goes through during those 20 seconds. For simplicity, we may say the number of behavioral states in the interval is ten. Later, that rat could be trained with an inter-stimulus interval of 100 seconds. Again, the theory posits that the rat will go through the same ten behavioral states. In either the case of the 20 s or 100 s trials, only the last few states will be strongly associated with reinforcement; thus, only the last few states should elicit responding. Because the number of states is constant, the response functions of the 20 s and 100 s trials will superimpose and conform to the properties of timescale invariance.

Timing of Compound Stimuli

Most research on the timing of responses as well as most timing theory is based on experiments in which a single, temporally informative, stimulus is presented at test. Situations in which the test stimulus to be timed consists of compound elements have received much less attention. This lack of investigation and theory is unfortunate because, in most instances, more than one stimulus in the environment conveys information about when a response is appropriate. For example, when stopped at a traffic light we may use the duration of the red light, the crosswalk symbol, and the movement of other cars in the intersection to anticipate the time to depress the accelerator. The lack of investigation in this area is also unfortunate given that there is extensive literature on the perception of compound stimuli. The following section highlights some of the major theories to come out of this literature.

Theoretical Approaches to the Perception of Compound Stimuli

An investigation into the timing of compound stimuli necessitates a discussion of how stimuli presented in compound are perceived by animals. Historically, there have been three main approaches to the investigation of compound stimuli perception. First, animals may learn about the stimuli individually. This is called the *elemental approach* to learning compound stimuli. On the other side of the issue is the *configural approach* to compound stimuli representation. This approach proposes that when stimuli are presented in compound, an animal learns about the stimuli as a single unit, not as individual elements. A modification of the elemental view, called the *unique cue approach*, provides an intermediate stance between the elemental and configural views. The unique cue approach assumes that an animal learns about the individual stimuli in the compound and, in the process, learns about an additional element that represents the entire stimulus configuration.

In the elemental perspective, each physical feature of the compound gains some associative strength and the associative strength of the compound equals the sum of associative strengths for all the individual features. This idea is most readily seen in the Rescorla-Wagner (1972) model of conditioning. As a demonstration of the elemental approach of conditioning, consider an experiment reported by Rescorla (1997) in a summation preparation. Rescorla trained rats to respond to conditioned stimuli A and B individually. In a subsequent test, A and B were presented together and level of responding was measured. Rescorla found that presenting the stimuli in compound resulted in more responding than when either A or B were presented alone. He accounted for this finding by saying that both A and B gained a certain amount of excitation during training. When the stimuli were presented together at test, the excitation generated by A was combined with the excitation generated by B resulting in stronger responding.

While the elemental approach of compound stimuli perception accounts well for results of many summation experiments (e.g., Kehoe, 1986; Forbes & Holland, 1985; Reberg, 1972), it has found criticism in preparations in which elements and compounds are trained with different consequences, as in negative patterning. As an example of negative patterning, Woodbury (1943) trained dogs to respond to A and B presented individually but not to presentations of the compound AB. In such cases, the Rescorla-Wagner model predicts higher responding to AB than to either A or B. This prediction is based on the additivity assumption of the Rescorla-Wagner model: If A and B have both been paired with the US and thus have acquired associative strength, then presenting A and B in compound will result in higher responding than to either A or B presented alone. Empirical results indicate that animals can be trained to discriminate between A and B presented individually and in compound (Deisig, Lachnit, & Giurfa, 2001; Lachnit & Kimmel, 1993; Woodbury, 1943).

To account for the inability of the Rescorla-Wagner model to predict negative patterning, Rescorla (1972, 1973) introduced the idea of a unique cue. This unique cue represents an additional element that develops during training and contains information about the entire configuration of the compound stimulus. The unique cue is assumed to have the same properties as the other elements in the compound. Thus, the three elements in an AB compound (A, B, and the unique cue of the configuration of AB) are all able to gain associative strength.

In the example of negative patterning above, the unique cue approach posits that A and B gain associative strength as they are individually reinforced. These same elements lose associative strength when they are not reinforced during compound trials. Furthermore, the unique cue AB also loses associative strength when it is not reinforced. Indeed, AB eventually becomes inhibitory (i.e., it predicts outcome omission rather than outcome occurrence). Thus, when the compound AB is presented, excitation from A and B should result in high levels of responding, but the inhibition acquired by the AB unique cue counteracts this excitation and, in consequence, responding is predicted to be lower to the AB compound than to either A or B presented individually.

The Rescorla-Wagner model makes other predictions that have not been empirically supported, even after assuming the presence of unique cues. For instance, if the elements being trained are A, B and C, and training consists of reinforced presentations of A, B and AB and nonreinforced presentations of ABC, the model predicts that animals will acquire the discrimination between A or B and ABC slower than the discrimination between AB and ABC (Pearce & Redhead, 1993). This is because the compound stimulus AB consists of three elements (i.e., A, B, and the unique cue of AB) that all share excitatory associative strength while A and B presented singularly each consists of only one element. Pearce and Redhead (1993) tested this prediction in an autoshaping procedure with pigeons as subjects, using colored rectangles as stimuli. Contrary to the prediction of the Rescorla-Wagner model, they observed that the discrimination between A or B and ABC was acquired faster that the discrimination between AB and ABC.

Based on this and other findings (see Kinder & Lachnit, 2003; Pearce, 1987; Redhead & Pearce, 1995), Pearce and his colleagues have argued for a different approach to the perception of compound stimuli called the configural approach. In the configural approach, stimuli presented in compound are viewed as a single unit that gains associative strength when presented with a US. Response generalization occurs to other stimuli depending on the similarity of the test stimuli to the originally trained CS. The experiment presented by Pearce and Redhead (1993) provides support for this view. The similarity between AB and ABC is greater than between A or B and ABC; in consequence, discriminating between AB and ABC should be more difficult than discriminating between A and ABC.

Elemental and configural views of compound stimuli learning have traditionally been set as contrary to each other. Recently, though, researchers have found that subjects can use both configural and elemental strategies and have identified conditions that influence which strategy is used. For example, Giurfa, Schubert, Reisenman, and Lachnit (2003) suggested that whether a compound is viewed elementally or configurally depends on the number of compound stimuli presentations the animals receive in training. They trained honeybees to respond to different colored disks in a Y maze task. In half of the training trials, there was a single disk (A) at the end of the reinforced arm of the maze, and the other arm was empty. In the remaining trials, two disks (BC) were presented at the end of one arm of the maze. Sucrose water was available as the reinforcer in a small tube hidden behind the disks. One group received six training trials (3 with A; 3 with BC) while other groups received 20 (10 A; 10 BC) and 40 (20 A; 20 BC) trials. All the animals were then tested to see which of two compounds they would choose, AC or BC.

According to the Rescorla-Wagner model, any given US can support a maximum level of conditioning or associative strength. This associative strength is divided among all the cues that are presented simultaneously and that predict the US. Following this assumption of the model, A (trained individually) should have more associative strength then either B or C (trained in compound) because B, C, and the unique cue of BC all share the associative strength available to the US while A acquires all of the available associative strength. For this reason, the model predicts that animals will choose the AC compound over the BC compound because AC would have approximately 130% of the available associative strength, thus being a better signal for the sucrose US than BC, which only has 100% of the available associative strength. On the other hand, because BC was already explicitly paired with the outcome, configural theories would predict the bees to choose BC. With few training trials (6), Giurfa et al. found that honeybees responded in a way consistent with the elemental view. Conversely, with a relatively large number of training trials (40) honeybees responded in a way more consistent with the configural view.

Research also suggests that the species of the subjects may also influence whether an elemental or configural coding strategy is used. Research with rats has shown that they tend to adopt an elemental strategy unless taught to do otherwise (Alvarado & Rudy, 1992). Analogous research with human subjects (Shanks, et al., 1998; Williams, Sagness, & McPhee, 1994) has demonstrated that they more readily adopt a configural strategy than an elemental strategy. Williams & Braker (1999) found that past experience with one strategy or the other is another factor that influences whether an elemental or configural strategy is used in humans. In one phase of their first experiment, they trained participants to use either a configural or elemental approach to predict the outcome of certain cues in a stock exchange task (i.e., they were asked to estimate whether a change in a certain stock was related to a change in the overall stock market). Specifically, one group of subjects learned that cues A, B, C, D, and CD (individual hypothetical stocks) were associated with the outcome (change in stock market) while cues E and DE were not. This group was the elemental group because the cue not associated with the outcome (E) was also not associated with the outcome when presented in compound with another cue (DE). For the other group, A, B, C, D and DE were associated with the outcome but E and CD were not. This was the configural group because the cue not associated with the outcome when presented individually (E) was associated with the outcome when presented in compound with another cue (DE). Williams and Braker then tested using the AB compound (These stimuli had never been presented in compound during training) to analyze the effect of the coding strategy training on how participants responded to a novel compound. They found that the type of coding strategy training the participants received had a significant effect on how they responded to AB. Specifically, the elemental group judged that the outcome (the stock market increasing) was more likely on the basis of AB increasing more than the configural group. This is because AB is presumed to follow the same course as CD did in the previous training. If C, D, and CD were followed by the outcome (as was the case for the elemental group), then AB should also be followed by the outcome when both A and B were followed by the outcome. If C and D were both followed by the outcome but CD was not, then the participants could have expected that AB would not be followed by the outcome because both A and B were.

Timing of Multiple Stimuli

Most research on timing with multiple cues has investigated cue competition phenomena, such as overshadowing and blocking. In this research design, multiple cues are trained and responding to single cues is measured. For example, Barnet, Grahame, & Miller (1993) trained water-deprived rats in a blocking paradigm. In the blocking design, responding to CS B is impaired if it is trained in compound with another CS, A, which is already a reliable predictor of the US (Kamin, 1968). For some of the rats, CS A was paired with a foot shock US in a forward manner and CS B was paired with the shock in a simultaneous manner. Other rats received training in which A was simultaneous paired with the shock and B was forward paired with the shock. All rats then received trials in which A was presented in compound with a novel stimulus, C, and forward-paired with the shock. At test, rats were presented with C and conditioned fear was measured. Responding to C was less (i.e., blocking was greater) when A was forward paired with the US in the initial phase of the experiment than when it was simultaneously paired, indicating that blocking was maximal only if the blocking (A) and blocked (B) CSs had the same temporal relationship with the US. Specifically, blocking was observed when both CSs A and C (in compound with A) received forward pairings with the US. On the other hand, if the temporal relationship between CSs A and C and the US was different (i.e., A received simultaneous training and C received forward training), blocking did not occur.

The results described above have been explained in the framework of the Temporal Coding Hypothesis (e.g., Matzel, Held, & Miller, 1988). The hypothesis can be summarized in four main arguments: (1) contiguity is sufficient for the development of an association between two stimuli, (2) information about the temporal properties of the stimuli is encoded as part of the association, (3) the form and timing of a response is influenced by these temporal properties, and (4) animals can integrate temporal information (i.e., they can form maps that imply a temporal relationship between events that have never been explicitly trained together). For example Arcediano, Escobar, and Miller (2003) trained human participants in phase one with pairings of A and B such that B immediately followed A. In phase two, B was backward-paired with an outcome stimulus. At test, stimulus A was presented alone. Participants responded simultaneously with A even though it was never paired with the outcome. An explanation for this result that is consistent with the temporal coding hypothesis is that participants were able to integrate information regarding the relationship between B and the outcome with information regarding the relationship between B and A. Presentations of A activated a representation of B in memory, including its temporal relationship with A. The representation of B, in turn, activated a representation of the outcome in memory, including its temporal relationship with B. These two representations of temporal relationships were integrated, indicating to the participants that the outcome should occur simultaneously with the occurrence of A.

A problem with the Temporal Coding Hypothesis is that it does not directly address how animals perceive a compound cue when the elements that make up the compound offer disparate information about the temporal location of the outcome. For example, if the elements that make up a compound stimulus signal outcome delivery at two different temporal intervals, how would animals resolve this conflict? One can anticipate several possible response strategies. For example, subjects could respond at both interval lengths. This response pattern represents the elemental prediction of response pattern because it indicates that subjects are responding to both of the elements in the compound individually. On the other hand, subjects could use a configural coding strategy. If this is the case, response pattern predictions are less clear. Responding could be evenly distributed throughout the interval, indicating that the subjects treated AB as a novel stimulus. Another possibility is that AB could generalize to A and/or B. This possibility would be evident if subjects respond at the interval associated with A more than to the interval associated with B or vice versa. Another possibility of a configural strategy is that subjects may respond somewhere between the intervals associated with A and B. This possibility is interesting because of the potential similarity of this finding to temporal bisection.

Besides questioning whether subjects will respond using an elemental or configural strategy, in this study we investigated the variables that influence which coding strategy is used. Specifically, we asked whether prior experience in which one strategy allows subjects to successfully master a discrimination influences which coding strategy they use in subsequent tests. In other words, if we train subjects to use an elemental strategy with one set of stimuli, will they use the elemental strategy with another set of stimuli? If we train subjects to use a configural strategy with one set of stimuli, will they use the configural strategy with another set of stimuli?

Preliminary Study

In a first attempt to investigate the effect of compound stimuli on response timing, we used 16 albino rats as subjects. They were repeatedly presented with four different stimulus configurations over 38 daily two-hour sessions. In this study, animals received training with two stimuli (A and B) which were 60 s in duration and which were reinforced with a sucrose pellet US. Two other stimuli (C and D) were meant to provide information regarding when the US was to be presented during A or B. If C preceded A (i.e., C→A) then the US was delivered 10 s after onset of A, and if C preceded B (i.e., C→B) the US was delivered 60 s after the onset of B. Conversely, if D preceded A (i.e., D→A) the US was delivered 60 s after the onset of A, whereas if D preceded B (i.e., D→B) the US was delivered 10 s after the onset of B. Probe trials intermixed with the training trials determined the extent to which the discrimination between the four different stimulus dyads was learned. It was expected that responding would peak at about 10 s when C preceded A and when D preceded B, and at 60 s when C preceded B and D preceded A.

Stimuli C and D functioned as *occasion setters* (Holland, 1992) that provided information about the temporal location of the US relative to the onset of CS A and B without directly eliciting a response. Previous research from our laboratory suggests that the compound presentation of stimuli that had each been directly associated with an outcome (CSs) resulted in responding at times appropriate for each stimulus (i.e., two peaks were observed). It was presumed that we would obtain a similar result if we tested CSs in compound in this study, namely that responding elicited by each of the elements would overcome the effect of presenting the elements in compound. Because the temporal expectation of an outcome was of interest to both the preliminary and current study, (not the direct response elicitation properties of the elements in compound) the compound stimuli were made up of occasion setting stimuli. Presumably, occasion setters provided the subjects with information regarding when to expect the outcome (and thus provided them with different temporal expectations relative to the occasion setter/CS dyads) without directly eliciting a response as the CS would.

Four probe trials (one each of C→A, C→B, D→A, and D→B) were presented in each of the daily training sessions. In these probe trials, the conditioned stimuli were 100 s in duration and reinforcement was withheld. We expected that responding in the probe trials would peak at about 10 s when C preceded A and when D preceded B and at 60 s when C preceded B and D preceded A. The dependent variable was head entries into the cull where food was delivered as counted by the breaking of an infrared beam at the mouth of the cull. Head entries were recorded into five s bins throughout each daily session. A 2 (group: Test A vs. Test B) X 4 (trial type) X 20 (response bin) repeated measure analysis of variance (ANOVA) was used to analyze data from the last day of training (Day 38). Only the main effect of bin was statistically significant, $F(19, 266) = 3.78$, $p < .01$, $MS_e = 5.74$. The effects of both trial type and group were not significant, $F(3, 42) = 2.49$, $p = .07$, and $F(1, 14) = .16$, $p = .699$, respectively. No interaction was significant all *Fs* < 1.31, all *ps* > .30. Of special interest is the observation that the Trial Type X Bin Interaction was not significant, $F(57, 798) = 1.01$, $p = .46$, $MS_e = 3.94$. This last finding suggests that the pattern of responding (i.e., the response peaks) of trials in which the US was delivered at 10 s (C→A and D→B trials) was not different from trials in which the US was delivered at 60 s (D→A and C→B trials). A visual inspection of these data (see Figure 2) indicates that, regardless of trial type, subjects' responses peaked at both 10 s and roughly around 60 s. In other words, the animals did not discriminate between the four stimulus configurations presented to them during training. Instead, they demonstrated elevated responding at both times of expected US delivery.

A test session was conducted after 38 days of training. The test consisted of the presentation of the CD compound followed by A for one group and B for the other (subjects had never experienced C and D together). The question was whether animals would respond in an elemental or configural manner when C and D were combined. Peak responding at both 10 and 60 s would indicate that they responded as if C and D were presented separately, an elemental strategy. A hypothetical response pattern of a configural strategy was less straightforward. Flat responding throughout the CS duration could indicate that the animals perceived the compound CD as a new stimulus that had not been paired with the US, a configural strategy. On the other hand, if a response pattern indicated that subjects' responses peaked at any single time other than the time appropriate for each element (e.g. between 10 s and 60 s) of the compound we could say that the subjects responded in a way consistent with a configural strategy.

A 2 (test dyad: CD→A, CD→ B) X 4 (trial) X 20 (response bin) repeated measure ANOVA was performed on the data collected during the 100 s test presentations of A or B. The main effect of group was not significant, $F(1, 14) = .001$, $p = .98$, $MS_e =$ 169.90. The main effect of trial was significant, $F(3, 42) = 13.28$, $p < .01$, $MS_e = 6.87$, as was the main effect of bin, $F(19, 266) = 3.49$, $p < .01$ $MS_e = 5.55$. Neither the pair-wise interactions (all $Fs < 1.16$), nor the overall interaction, $F(57, 798) = .83$, $p = .81$ $MS_e =$ 5.13 were significant. Inspection of the test data (see Figure 3) revealed that responding peaked near both 10 s and 60 s, as would be expected by the elemental account. This result must be tempered by the fact that, in training, both A and B presented alone produced peak responding at 10 s and 60 s regardless of which occasion setter preceded them. That is, the temporal discrimination was not sufficiently developed before the test trial. Therefore, the results of the test are ambiguous, and they could be viewed as evidence of a lack of discrimination rather than evidence that the animals processed the CD compound elementally.

The Present Experiment

This study was an attempt to investigate the same experimental question that was investigated to no avail in the preliminary study but with humans as participants. Humans were used for two reasons. First, we wanted to change the experimental design to study the effect of coding strategy training, a procedure that has been shown to induce human participants to use either an elemental or configural strategy in subsequent tasks (e.g., Williams & Braker, 1999). Second, conducting parametric manipulations, if needed, would be easier with humans than with nonhuman animals because completing each human study would take significantly less time. Thus, the questions addressed here were simply (1) how will humans respond when cues presented in compound provide disparate information about the temporal location of an outcome and (2) can previous experience (coding strategy learning) effect responding?

In this experiment, participants experienced two phases of training (strategy learning and discrimination learning) and one test phase consisting of trials in which a compound stimulus was presented. Participants were divided into four groups. The elemental group received coding strategy training that should incline participants to respond to the compound in an elemental way. The configural group received strategy training that should incline participants to respond in a configural way. The configural control and elemental control groups received training that was explicitly meant not to influence them to adopt either an elemental or configural strategy. The control groups were called configural control and elemental control on the basis of which cues were associated with the outcome; C and D for the configural control group; C and E for the elemental control group.

In the strategy learning phase, participants in the configural group were presented with cues C, D, E, and CD, of which only C and D were paired with the outcome. Thus, it was presumed that when other elements (e.g., A and B) that had both been paired with the outcome were presented in compound, participants in this group expected a lack of outcome. Another group of participants (the elemental group) was also presented with C, D, E, and CD. For this group, only C and E were paired with the outcome. Thus, one element (C) predicted the outcome and the other (D) always predicted the absence of the outcome. When A and B were presented in compound, it was presumed the participants would consider the prediction of each element individually. Two control groups received similar training as both the elemental and control group, except that the compound stimulus (FG) they were presented was independent of the elements presented individually. This task was based on an experiment by Williams and Baker (1999) that was mentioned previously. A difference between our study and the study of Williams and Braker was that we omitted trials of DE. Presentation of DE was omitted from our study because it was assumed that configural and elemental coding strategies could be learned without it. The logic for this assumption, along with a detailed description of our design, is given in the procedure section below.

Following strategy training, all participants experienced a discrimination training phase in which the outcome was presented at either the beginning or the end of the training stimulus. The training stimulus, X, was preceded by one of two additional stimuli, occasion setters A or B, which indicated whether the outcome was presented at the beginning or end of the stimulus. Thus, when A preceded X, participants were expected to respond at the beginning of the duration of X. When B preceded X, participants were expected respond at the end of the duration of X. At test, the two occasion setting stimuli were presented in compound preceding presentation of the training stimulus without the outcome. Subjects were asked to indicate when they expected the outcome to occur relative to the training stimulus.

METHODS

Subjects and Stimuli

The sample of this experiment consisted of 120 undergraduate students at Auburn University, randomly assigned to one of four experimental groups (40 in the configural group, 39 in the elemental group, 20 in the configural control group, and 21 in the elemental control group). All subjects received extra credit in a Psychology class for participating in this study.

Stimuli were presented on computer screens that were arranged in a small room. Two of the computers were against one wall of the room with a plywood divider between them and two against the opposite wall with a plywood divider between them. All four computers ran with Pentium II processors. Stimuli C, D, E, X, CD and FG were presented in a gray square in the upper half of the computer screen. These stimuli were presented for 18 s duration and consisted of shapes of various colors, namely a green cross (C), a brown square (D), a purple hexagon (E), a green trapezoid (X), an orange triangle (F), and a pink inverted ‘L’ (G). The physical features of A and B (a cyan ‘X’ and a yellow circle) were counterbalanced across groups. A and B were presented for three s and were terminated two seconds before the presentation of X. The outcome stimulus, O, was presented in a similar gray square in the lower half of the screen. Stimulus O was a red star, 6 s in duration.

Procedure

A graphical representation of the training contingencies across phases is presented in Table 1. Participants were asked to respond by pressing the keyboard spacebar when they expect the outcome to occur. Responses were recorded in one-second bins. The maximum number of responses recorded per second of continual pressing was 130, based on the processing speed of the computers.

Strategy Learning Phase. This phase was divided into an observation task and a test task. In the observation task, all subjects received one presentation each of C, D, CD, and E. Participants in the elemental group received presentations of C and E each paired with the outcome. The other element (D) predicted the absence of the outcome. Participants in the configural group received presentations of C and D paired with the outcome. Both elements associated with the outcome predicted the absence of the outcome when presented in compound. We assumed that these pretreatments resulted in different coding strategies because only one strategy could be used to successfully make the discrimination between cues associated with the outcome and cues associated with the absence of the outcome. For the elemental group, one element (D) was associated with the absence of the outcome whether it was presented individually or in compound with another stimulus (C). Thus, participants in this group could discriminate on the basis of the presentation of D. In the configural group, both elements of the non-reinforced compound were reinforced when presented individually. Thus, participants in the configural group could discriminate between reinforced cues and nonreinforced cues on the basis of whether the stimulus was an element or a compound. Participants in the configural control group received the same treatment as the configural group except that the compound stimulus presentation consisted of two novel elements (F and G) instead of CD. Likewise, the elemental control group received the same treatment as the elemental group except that the compound was FG instead of CD. The outcome was delivered at the ninth second of stimulus presentation, effectively in the middle of the stimulus duration.

After each observation task, participants were asked to respond if and when they expected the outcome during the stimulus presentation by pressing the space bar on the computer keyboard. This was done to test participants' understanding of the contingencies in place and to provide feedback for the subject. The feedback consisted of a timeline that represented if and when the outcome should have been expected in the stimulus duration compared to when the participant actually responded. All instructions for the observation and test tasks, as well as the feedback messages, are presented as Appendix A.

When participants sat in front of the computer screen, they were presented with a general description of the task and instructions to pay attention to the task and respond when they expected the outcome. They then were presented with the observation task in which they observed the relationship between each of the four strategy learning cues (presented one by one) and the outcome. They were then presented with each of the cues again and were asked to respond when they expected the outcome. Following this test task, another observation task began, in which the discrimination phase cues were presented one by one and associated with the outcome. They were then asked to respond when they expected the outcome when presented with the compound presentation of both of the discrimination learning phase cues as well as each of the cues individually.

Discrimination Learning Phase. Following the strategy learning phase, all participants received three cycles of discrimination learning, each composed of one A→X trial and one B→X trial (a cycle consisted of the observation task followed by the test task). A and B were three s in duration and terminated two s before the onset of X (i.e. there was a two s gap between termination of A/B and onset of X). Stimulus O occurred at either the beginning or the end of X, depending on whether A or B preceded X. When A preceded X, the outcome was presented during seconds 1-7 of the duration of X. When B preceded X, the outcome was presented during seconds 13-18 of the duration of X. The order of A and B presentations was counterbalanced within groups.

During the test task, participants received a single presentation each of A→X, B→X, and AB→X, and they were asked to make a space bar response when they thought the outcome should occur. A→X and B→X observation and test tasks always preceded AB→X observation and test tasks, but their order was counterbalanced between participants. For each participant, the A→X and B→X test tasks followed the same order as the observation tasks. The temporal location and duration of participants' responses were recorded for each of these trials, but feedback was not given. It was expected that participants would respond correctly to tests of both A and B relative to X. Specifically, in the A→X test, participants should have responded in the initial portion of the duration of X. Similarly, the B→X test should have resulted in responding at the end of the duration of X. The test of the compound stimulus AB is of primary interest to this study. If the strategy learning phase of the experiment influences how the participants perceive the AB compound, the pattern of responding for the elemental group should be different from the response pattern of the configural group.

RESULTS

Test trials of the stimuli presented in the coding strategy learning phase confirm that the appropriate discriminations were learned by each group. The result of primary interest was that the configural group responded to the AB→X test differently than did either the elemental or control groups. The configural group responded most in the middle segment of X, whereas the other two groups responded most in the initial segment.

Participant's responses during the test presentations of C, D, CD, E, FG, and X were recorded as the number of responses per second. The duration of these stimuli was divided into three segments for analyses, namely the initial, middle and final 6 s of the stimulus duration. Individual participants' responses per second were summed across interval segments. Participants responded to all stimuli in a manner consistent with the training they received. The following analyses confirm this conclusion.

Coding Strategy Phase

Stimulus C. A 3 (segment: initial vs. middle vs. final) X 4 (group: elemental vs. configural vs. elemental control vs. configural control) repeated measure ANOVA for the test of C, the stimulus that was associated with the outcome in all four groups. Accordingly, there was a significant main effect of segment, $F(2, 232) = 40.43$, $p < .01$, $MS_e = 58826$, as well as a significant Segment X Group interaction, $F(6, 232) = 2.25$, $p = .04$, $MS_e = 58826$. The main effect of group was not significant, $F(3, 116) = 1.54$, $p =$

.21 $MS_e = 37636$. These results are represented graphically in Figure 4. A post hoc test using Bonferroni's adjustment revealed that responding in the middle segment was, for the most part, significantly higher than in either the initial or final segment (all $ps < .01$) for every group except for the configural control group, for which the initial/middle segment comparison ($p = .09$) and the middle/final segment comparison ($p = .07$) were not significant. In addition, the initial/middle segment comparison for the configural group ($p = .09$) and the middle/final segment comparison for the elemental control group ($p = 1.00$) were not significant. These exceptions account for the significant interaction effect. The effect of segment was expected because the outcome occurred during the middle segment of the observation task for all four groups. Similarly, the lack of significant main effect for group was expected because each group received the same treatment in this trial.

Stimulus CD. CD was not associated with the outcome in any group. Accordingly, neither the main effect of group, $F(3, 116) = 2.26$, $p = .08$, $MS_e = 62601$, nor the Group X Segment interaction $F(6, 232) = .78$, $p = .58$, $MS_e = 21837.33$, were significant. However, there was a significant main effect of segment, $F(2, 232) = 11.98$, $p < .01$, $MS_e = 21837.33$. A post hoc test using a Bonferroni adjustment revealed that the significant main effect of segment was due to elevated responding in the middle segment from the elemental group. Both the initial/middle ($p < .01$) and middle/final ($p = .02$) segment comparisons were significant for the elemental group. It should be noted that responding for each group in the CD trial was much less than responding in the C trial (see Figure 4), indicating that while the effect of segment was significant within the CD trial, responding to C was much higher than responding to CD. The effect of segment in the CD compound test trials may have been due to the fact that at least one element in the compound was associated with the outcome. Thus, the differential responding to the middle segment may be accounted for by generalization of responding from the reinforced element(s) to the compound.

Stimulus D. Stimulus D was associated with the outcome for the configural and configural control groups, but not the elemental and elemental control groups. The ANOVA revealed a significant main effect of segment, $F(2, 232) = 47.13$, $p < .01$, $MS_e = 34874.44$, group, $F(3, 116) = 24.35$, $p < .01$, $MS_e = 36584.29$, and a significant Segment X Group interaction, $F(6, 232) = 8.56$, $p < .01$, $MS_e = 34874.44$. A post hoc test with Bonferroni adjustment confirmed that responding in the middle segment was significantly greater than either the initial or the final segments for both the configural and configural control groups (all *ps* < .01). For the elemental and elemental control groups, responding in the middle segment was not significantly different from either the initial or the final segments (all *ps* > .93).

Stimulus E. Stimulus E was associated with the outcome in the elemental and elemental control groups, but not in the configural and configural control groups. This ANOVA revealed that the effect of segment, $F(2, 232) = 35.20$, $p > .01$, $MS_e = 35504.81$, and group, $F(3, 116) = 13.04$, $p < .01$, $MS_e = 60896.51$, and the Segment X Group Interaction, $F(6, 232) = 2.27$, $p = .04$, $MS_e = 35504.81$, were all statistically significant. A post hoc test with a Bonferroni adjustment confirmed that the elemental and elemental control groups responded at higher levels in the middle segment than in either the initial or the final segments (all *ps* < .01). The configural and configural control groups did not respond significantly more in the middle segment than in either the initial or the final segment (all *ps* > .09).

Discrimination Learning Phase

Functionally, the elemental control and the configural control groups experienced the same treatment. Two elements (C and D or E) were each associated with the outcome and two different elements (F and G), presented in compound, and were not associated with the outcome. It was assumed that, because these groups received the same treatment as it concerns the AB→X test, their data could be pooled for analysis of the test phase of discrimination learning. To test this assumption, a 2 (configural control vs. elemental control group) X 3 (trial) X 3 (stimulus segment) repeated measure ANOVA was performed on the AB→X test data with the purpose of testing the effect of group, specifically the effect between control groups. Neither the effect of group, $F(3, 39) = .07$, $p = .80$, $MS_e = 129914.90$ nor the Group X Segment interaction, $F(2, 78) = .18$, $p = .84$, $MS_e = 31355$ were significant. The assumption of equality was supported by this result, so the configural control group and the elemental control group were pooled into one control group.

AB→X test. A 3 (trial) X 3 (segment: initial vs. middle vs. final) X 3 (group: configural vs. elemental vs. control) repeated measure ANOVA was conducted on the data recorded in the AB→X test trials. This ANOVA revealed that the main effects of trial, $F(2, 234) = 6.23$, $p = .01$, $MS_e = 39180$, and segment, $F(2, 234) = 47.06$, $p < .01$, $MS_e = 54944$, were significant. Likewise, the interaction between segment and group was significant $F(4, 234) = 3.13$, $p = .02$, $MS_e = 54944$. No other interaction was significant, nor was the main effect of the group significant. The main effect of trial may be evidence of a learning curve as the participants experienced the training task and of a resulting attrition of responses. Twenty-eight participants withheld from responding in trial one compared to 43 in trial 2 and 44 in trial 3. Alternatively, the effect of trial may be an indication that participants changed coding strategy across trials. Previous research (e.g., Girufa et. al., 2003) has suggested that the number of exposures to a compound stimulus effects whether the stimulus is processed using an elemental or a configural strategy. As exposure to the compound CS increases, subjects become more likely to process the compound configurally. To account for findings like this, McLaren and Mackintosh (2000) use the process of stimulus *unitization*. The unitization of a compound means that, with repeated exposure, the common features (often the gross features like size or brightness) of two stimuli in compound are processed with less variability across trials than the unique features. This results in generalization of the features common to both elements. Thus, with repeated exposure, the elements of the compound are treated as if they are made up of the same features. It could be that on the third trial, our participants responded to the shared features of the individual elements rather than to the unique features, resulting in the trial effect observed. This explanation seems less likely than extinction because, though the effect of trial was significant, the effect of the Trial X Group interaction was not. Each group responded in a consistent pattern across trials. Only the overall levels of responding within trials changed (decreased) across trials. This pattern of responding can be seen in Figure 5 of Appendix B.

Because we were primarily interested in responding resulting from the accumulated experience after the three training cycles, another ANOVA for the data obtained in trial 3 was run with group and stimulus segment as factors. This analysis revealed that the main effect of segment, $F(2, 234) = 18.71$, $p < .01$, $MS_e = 36353.58$, and the Group X Segment interaction, $F(4, 234) = 3.85$, $p < .01$, were both significant. The main effect of group was not significant, $F(2, 117) = .10$, $p = .90$, $MS_e = 52790.612$. A post hoc test using a Bonferroni adjustment confirmed that the configural group responded significantly more during the middle segment than either the initial segment ($p = .02$) or the final segment ($p = .01$). The elemental group responded similarly in both the initial/middle segment and the middle/final segment comparisons (*ps* = 1.00), though the initial/final segment comparison approached significance ($p = .053$). For the control group, the middle/final segment comparison and the initial/final segment comparison were significant ($p < .01$) but the initial/middle segment comparison was not significant ($p = 1.00$).

A plot in which time is represented on the horizontal axis, average responding on the vertical axis, and groups plotted as separate lines (Figure 6) reveals that the grouped data have distinct peaks of responding, especially in trial 3. We computed the time (in seconds) of peak responding by performing an iterated median computation, based on the descriptions of Cheng and Roberts (1991) and Roberts (1981). The one-second interval that contained the median response (the median second) was obtained and compared to the middle second (second 9) of the stimulus duration. If there was a difference between these two seconds (i.e., the middle second subtracted from the median second did not equal zero), a new median second was obtained using the distribution of responses in an interval twice as long as the originally obtained median second. If the new median second was different from the original median second, the process was repeated until the median response came from the same second as the middle of twice the preceding interval. This was, then, the second of peak responding. This process was completed for each participant's response distribution for each of the AB→X trials. A simple ANOVA was analyzed comparing the second of peak responding across the three groups. The effect of group approached significance, $F(2, 56) = 2.56$, $p = .09$, $MS_e = 13.60$. Figure 7 displays the data from this analysis as mean peak time for the different group at trial one, two, and three.

A→X trial. In order to test asymptotic responding to the A→X test trials, the third test trial was analyzed by way of a 3 (group) X 3 (segment) ANOVA. This analysis revealed that the main effect of segment $F(2, 234) = 54.49$, $p < .01$, $MS_e = 51406$, was significant (see Figure 7). On the other hand, neither the main effect of group, $F(2, 117) = 1.75$, $p = .18$, $MS_e = 16962$, nor the Group X Segment interaction, $F(4, 234) = .99$, $p = .41$, $MS_e = 51406$ were significant. Post hoc test using a Bonferroni adjustment confirmed that, in general, responding in the initial segment was greater than responding in the middle segment which, in turn, was greater than in the final segment (*ps* < .03) for each group except that the initial/middle for both elemental (p = 1.00) and control ($p = .78$) groups did not achieve significance. The distribution of responses for each A→X test trial is represented in Figure 8.

B→X trial. To test asymptotic responding to the B→X trials, the third test trial was analyzed by way of a 3 (group) X 3 (segment) ANOVA. This analysis revealed that the main effect of segment, $F(2, 234) = 24.80$, $p < .01$, $MS_e = 59172$ was significant (see Figure 7). Neither the main effect of group, $F(2, 117) = .36$, $p = .70$, $MS_e = 23434$, nor the Group X Segment interaction, $F(4, 234) = .93$, $p = .45$, $MS_e = 59172$, were significant. Post hoc comparisons with a Bonferroni adjustment for each group between the three stimulus segments confirmed that responding was greater in the middle segment than in the initial segment for both the configural ($p < .01$) and control ($p < .01$) groups. No other comparisons with groups were significant. Of specific note, the middle/final segment comparisons were not significant for any group. It was expected that participants would respond greatest during the final segment, because the outcome was delivered in the final segment in B→X trials. This result indicates that, while they did delay responding until the middle segment, participants may not have had enough training to correctly specify the appropriate response time (the final segment) for the B→X trials. The distribution of responses for each B→X test trial is represented in Figure 9.

CONCLUSION

The finding of central interest to this study was that participants in the configural group responded more in the middle segment of the AB→X stimulus duration than in either the initial or the final segment. This result is interesting because the middle segment of X was not associated with the outcome during training. If participants in the configural group had perceived AB as a mere sum of its elements, we would expect responding at the appropriate initial, final, or both initial and final segments. It seems clear that AB was perceived as something different from the elements A and B. Why this particular perception influenced participants in the configural group to respond during the middle segment of the stimulus is an interesting question. The result may indicate an averaging of the two temporal expectations associated with the elements A and B. This account can be viewed as consistent with SET in that the expectations for A and B have been quantified in the participants' perception as the number of pulses generated by an internal clock. The two temporal expectations were then averaged in reference memory by a process not described by SET.

Another interesting finding of this experiment was that the elemental group and the control group responded similarly across stimulus segments. Both groups responded highest in the initial segment (the stimulus segment associated with the outcome when A was presented) and decreased responding slightly in the middle segments and significantly in the final segment. It appears that participants in the elemental and control groups responded to element A of the AB compound. The elemental group was pre-trained to respond in such a way in the strategy learning phase, so it is not surprising that they responded to an element of the compound. They may have responded to A and not B for a number of reasons. First, each cue that was associated with the outcome in the strategy learning and the discrimination learning phases was only associated with one occurrence of the outcome. The participants may have expected to only respond for one interval per trial. Because participants expected A to occur before B, they may have responded to A and then reasoned that the opportunity to respond was over for the trial. Alternatively, participants may not have learned to respond appropriately to B in training. The statistical analyses indicated a lack of temporal specificity of responding in the last B→X test trial, meaning that participants may have wished to respond to B but lacked the temporal discrimination necessary to do so.

While the elemental group was trained to process compound stimuli using an elemental strategy, the control group had no such training. It appears that participants in the control group were using an elemental strategy by default. This explanation of our results is at odds with studies reporting that humans generally perceive compounds configurally (e.g., Shanks, et al., 1998; Williams, et al., 1994).

Task difficulty may be an important factor in the discrepancy between these previous findings and the findings of this study. Regehr and Brooks (1995) asked participants to sort cards into categories based on two prototypes. When the cards were presented one at a time, participants sorted them on the basis of *family resemblance*, in other words, the overall similarity to the prototype. Other participants were asked to perform the same task, but were only allowed to see one card at a time. These participants sorted them on the basis of single elements. This second task was considered more difficult because the participants were able to compare the cards to each other as well as to the prototypes. Thus, when the task was simple, participants used a configural strategy. When the task was more difficult, participants used an elemental strategy. Our task could be viewed as more difficult than the negative patterning task of Williams et al. (1994). Their task requested participants to indicate only whether they expected the outcome stimulus in relation to the compound cue. Our experiment required participants to indicate when the outcome was expected in addition to asking whether they expected the outcome. This temporal discrimination requirement may have influenced the control group, who had not experienced strategy training, to respond using the elemental strategy.

In addition to gathering categorization data, Regehr and Brooks conducted post-task interviews in order to investigate whether participants were aware of the strategy they used. A procedure like this may be informative in our task. For example, in a replication we could ask participants when they responded when presented with the various test trials, and why they responded at that time. This would provide us with at least two more pieces of information: (1) It would allow us to compare participants' response time and duration data to the times that they thought they were responding. The degree of discrepancy between these measures would indicate how well the discrimination was learned in the case of A→X and B→X trials as well as the strategy learning stimuli. It would also tell us whether actual response times are consistent with how the participants *meant* to respond. (2) It could provide additional information regarding coding strategy. For instance, if a participant reported, "I knew that A predicted the outcome at one time and B at another, so when A and B came together I decided to respond between the two." This would tell us that the participant considered each element individually and solved the compound problem using an averaging strategy.

One final interesting finding came from the peak response analysis. Mean peak times at the first trial were 8.44 s for the configural group, 7.75 s for the elemental group, and 7.83 s for the control group. By the third trial, mean times were 8.94 s for the configural group, 7.85 s for the elemental group, and 6.61 s for the control group. The mean peak times of the third trial are interesting because of their proximity to the arithmetic mean (9.50 s) and geometric mean (7.37 s) of the two reinforced intervals. Research that investigates temporal bisection generally reports that the indifference or bisection point is close to the geometric mean of the two interval standards. Perhaps manipulating the coding strategy used to process compound stimuli will affect the intrinsic mathematics participants use to average temporal expectations rather than affecting whether or not the elements are perceived as something different from compound. While this experiment does not address this idea directly, the procedure might be altered in such a way as to pit these explanations against each other.

At its center, the discrimination learning phase of our experiment is a summation test. A summation test is any procedure in which two or more elements are trained individually and tested in compound. This test is commonly used in research on conditioned inhibition, but can also inform research regarding configural vs elemental processing because configural and elemental theories predict opposite results in summation. Elemental theories like the Rescorla-Wagner model predicts that when two elements (A and B) are trained to asymptote and then tested in compound, the associative strength of the AB compound would be the sum of the associative strengths of A and B (i.e., overexpectation would emerge). A problem with this prediction is that the elements had already been trained to asymptote individually (that is, each element has obtained the maximum associative strength supportable by the US). Therefore, when the elements are presented in compound, responding does not double as would be expected by the summation of the associative strength of the elements. Kremer (1978) found support for an elemental account of summation by testing A and B individually after AB training. The test of the elements was found to elicit less responding than the elements had before training of the compound. According to the Rescorla-Wagner model, this decrease in responding meant that each stimulus had acquired half of the associative strength available from the US during compound training.

The configural theory account of stimulus summation is in contrast to the elemental account. According to the configural theory of Pearce, the AB compound stimulus will accrue associative strength that is independent of the associative strength of its elements. Summation of trained elements should not result in overexpectation as the Rescorla-Wagner model predicts, because AB represents a pattern of stimulation different from either A or B. Likewise, a test of the individual elements after compound stimulus training should not reveal degradation in responding relative to pre-compound training responding because trials of A and B, individually presented, are independent of trials in which they are presented in compound. To account for the findings like those of Kremer (1978), Pearce (2002) posits that responding to the first presentation of the compound stimulus after element training can be attributed to generalization. There are physical similarities between trials of A or B and trials of AB that facilitate generalization between the trials. In addition, Pearce (2002) argues that the overestimation in summation effect reported by Kremer (1987) and others may not be as robust as once thought. He and his collogues have failed to obtain less responding to A and B after AB training.

It is important to note a difference between summation research and the current experiment. Studies of summation traditionally have looked at total responding within a trial. If the total number of responses to AB is equal to the total responses to A or B, then stimulus generalization has occurred according to configural accounts. The current experiment does not inform the elemental vs configural debate on the basis of total responding (indeed, total responding was not significantly different between groups). Instead, the temporal location of responding within a trial was assessed in order to discover whether a group with configural training responded at a different location than did a group with elemental training. This difference reveals not only a departure in method and measurement, but also an alternative approach to research in elemental and configural processing of compounds. The question addressed by this approach is if two elements are both reinforced, but at different times, when will participants respond if the elements are presented simultaneously? The results of the current experiment provide evidence that previous experience with configural or elemental strategies is a factor that influences the answer to this question.

There are theories of response timing that make allowance for the timing of multiple events. The multiple oscillator theory of Church and Broadbent (1991) is one such theory. This theory allows for the simultaneous timing of multiple cues by means of a various oscillators working in parallel. When a reinforcer is delivered on a regular schedule (FI or FT schedule), the overall pattern of oscillator activation at the time of reinforcement is stored in memory. The duration of two independent stimuli can be timed, because each reinforced duration in memory is represented by a different pattern of oscillator activation. Each memory can be compared to the pattern of activation at any given moment of the current timed. While this theory accounts for animals' ability to time multiple stimuli, it does not consider the effect of presenting stimuli in a summation test as was our task.

Finally, this experiment was framed as a replication of a preliminary study that used rats as subjects. In the preliminary study, the subjects responded at the temporal expectations of both elements when they were presented in compound. We were not able to rule out the lack of discrimination between the elements as an explanation for this pattern of responding. The inclusion of the strategy learning phase in the current experiment allowed us to train different groups to respond elementally or configurally. This finding provides hope that rats can also be trained to use one strategy or another. Specifically, we would expect rats to respond in an elemental way based, in part, on the research of Williams and Braker (2002), but we may be able to train them to respond in a way analogous to the configural group of this experiment using a phase like the strategy learning phase. Williams and Braker found that rats do not respond in a configural way very readily, but their task did not require a temporal judgment as ours did.

This experiment informed further research with non-human animals in some other ways. For example, in our preliminary study, rats had to learn a conditional discrimination in which no one occasion setter consistently predicted the outcome at either the long or the short interval. Likewise, no one CS consistently predicted the outcome at either the long or the short interval. This step was taken to ensure that no one cue became overly salient, overshadowing the other element when presented in compound. This task may have been too difficult for the animals. In the current study, only one CS was used and each occasion setting element always predicted the outcome at the same interval. We could modify the animal task to mirror this study and maintain counter-balancing by varying which stimulus was occasion setter A and which was occasion setter B.

In summary, this experiment found that training participants to use a either an elemental or a configural strategy when presented with a compound stimulus of which the elements provide disparate information about the timing of an outcome influences how they respond to that stimulus. The configural group seems to have processed the compound by averaging the expectations of the outcome associated with elements while the elemental and control groups responded to one element of the compound at the exclusion of the other. This finding can provide information to research lines investigating the elemental vs configural processing debate as well as the timing of multiple stimuli.

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Appendix A – Experimental Instructions and Feedback

INSTRUCTIONS

Please, carefully read the following instructions.
To advance the instructions, press the right cursor key on the keyboard (→), once for each screen. If you need to go back, press the left cursor key (←).

In this experiment, you will be presented with two sets of situations. The first set is composed of four PRACTICE SITUATIONS in which you will learn how to perform in this experiment. You will first observe the four situations; after completing the observation, you will receive a test followed by feedback about your performance. That is, you will see what response we expected from you and what response you actually gave. The second set is composed of two RELEVANT SITUATIONS. Just as with the practice situations, you will complete an observation phase and a test phase, but you will not receive feedback after the test. Because the relevant situations are more complex than the practice situations, you will go over the second set three times. Completing the two sets of situations usually requires about 25 minutes, but it is normal that some people finish before others.

During each observation phase, you will have to OBSERVE and LEARN how different signals (colored shapes on your computer screen) are related to the presence or absence of a target (a red star on the screen). After completing the observation phase, the test phase will begin. In the test phase, you will have to RESPOND by holding down the space bar on your computer's keyboard during the time you believe the target (the red star) should appear on the screen. You will have to guess because the red star will not be displayed during this test phase. Thus, you will have to infer, based only on how the signals were related to the target during the observation phase, not only whether the red star should appear, but also when and for how long

You will always see two squares on the computer's screen. The signal or signals that may help you guess when the target is going to appear will be displayed in the top square. The target (the red star) will be displayed in the bottom square. Remember that your response during the test phase must be based only on what you learned about the relationships between the signals and the target.

Please observe how the signal (a colored shape) is related to the presence of the target (a red star). Remember that later on you will have a test phase in which the red star will not be displayed, but you will have to decide WHETHER, WHEN, and for HOW LONG you have to press the space bar. During the test phase, you must hold down the space bar ONLY during the time that you think the red star should be displayed on the screen.

Press the ENTER key when you are ready to begin with this observation phase.

PRACTICE SITUATION: OBSERVATION PHASE

Please observe how the signal (a colored shape) is related to the presence of the target (the red star).

Press the ENTER key when you are ready to begin with this observation phase.

PRACTICE SITUATION: TEST PHASE

Now, you will begin the test phase. You will have to decide WHETHER, WHEN, and for HOW LONG to hold down the space bar. The red star is not programmed to appear; however, you can make it appear by holding down the space bar. Your goal is to make the red star appear during the time that you expect it, based on how the signal was related to the target during the observation phase. To do this, you should hold down the space bar ONLY during the time that you guess the red star should be displayed on the screen and not at any other moment. Remember that your decision to respond or not to respond, when to respond, and for how long should be based only on what you have learned about the relationships between the signal and the target.

Press the ENTER key when you are ready to begin with this test phase.

PRACTICE SITUATION: TEST PHASE

Now you will be shown another signal. Hold down the space bar ONLY during the time that you expect the red star to appear based on how the signal was related to the target during the observation phase.

Press the ENTER key when you are ready to begin with this test phase.

RELEVANT SITUATION: OBSERVATION PHASE

You have finished the practice situations. Now, you will be presented with two more complex situations in which multiple signals will be presented during the observation phase. Your task will be to observe how the signals are related to the target during the observation phase in order to guess when the target should be expected to occur during the test phase. Remember that during the test phase the red star will not be displayed, but you will have to decide WHETHER to press the space bar, WHEN, and for HOW LONG based on what you learn during the observation phase.

RELEVANT SITUATION: OBSERVATION PHASE

Now you will go over the relevant situation again. Please observe how the signal (a colored shape) is related to the presence of the target (the red star).

Press the ENTER key when you are ready to begin with this observation phase.

RELEVANT SITUATION: TEST PHASE

Now, you will begin the test phase. As before, the red star is not programmed to occur; however, you can make it appear by holding down the space bar. You will have to decide WHETHER, WHEN, and for HOW LONG to hold down the space bar to make the red star appear ONLY during the time that you guess it should be displayed based on what you learned during the observation phase.

Press the ENTER key when you are ready to begin with this observation phase.

RELEVANT SITUATION: TEST PHASE

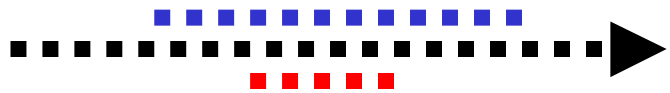
Now you will be shown another signal. Hold down the space bar ONLY during the time that you expect the red star to appear based on how the signal was related to the target during the observation phase.

Now, you will begin the test phase. During this phase, only one of the signals (the BLUE CROSS) will be displayed, and based on what you learned about this signal you will have to decide WHETHER, WHEN, and for HOW LONG to hold down the space bar. You must keep on mind that the blue cross may not be directly related to the red star, but it may help you predict the moment at which the red star should be expected to appear. As with the previous situations, the red star is not programmed to appear, but you can make it appear by holding down the space bar. Remember that you should hold down the space bar ONLY during the time that you guess the red star should be displayed on the screen and NOT at any other moment.

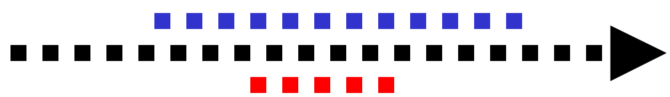
FEEDBACK

You have just finished the test for this situation.

Below, you have the events as presented during the OBSERVATION PHASE. The Signal is represented by the blue dots above the time line and the target (the red star) by the red dots below the time line.



During the TEST PHASE, the same signal appeared (represented by blue dots above the time line) and we expected you to hold down the space bar only during The time the target was expected to appear (red dots below the time line). Below The red dots, you can observe when you held down the space bar (light and dark green dots). Your goal was to make your response match the red dots (time in which the target was expected to appear). Dark green dots represent this matching (correct response) and light green dots represent a mismatch between Your response and the expectation of the target (wrong response).



Press the ENTER key to continue

Appendix B—Figures

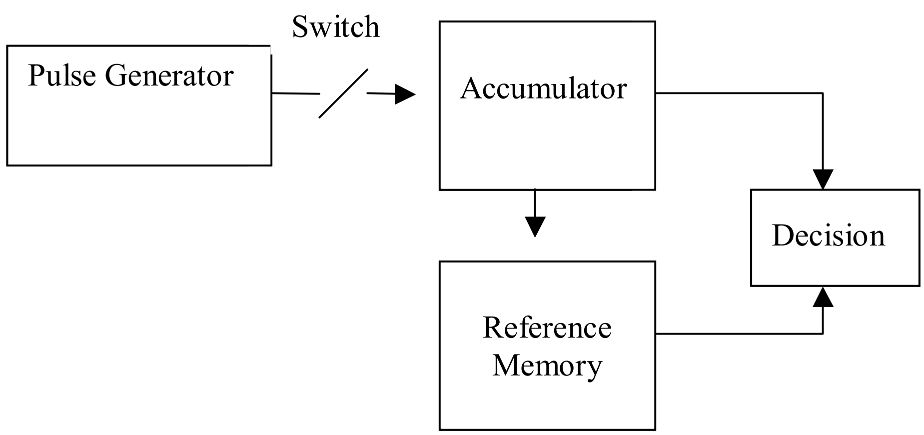


Figure 1. Model of Scalar Expectancy Theory (SET)

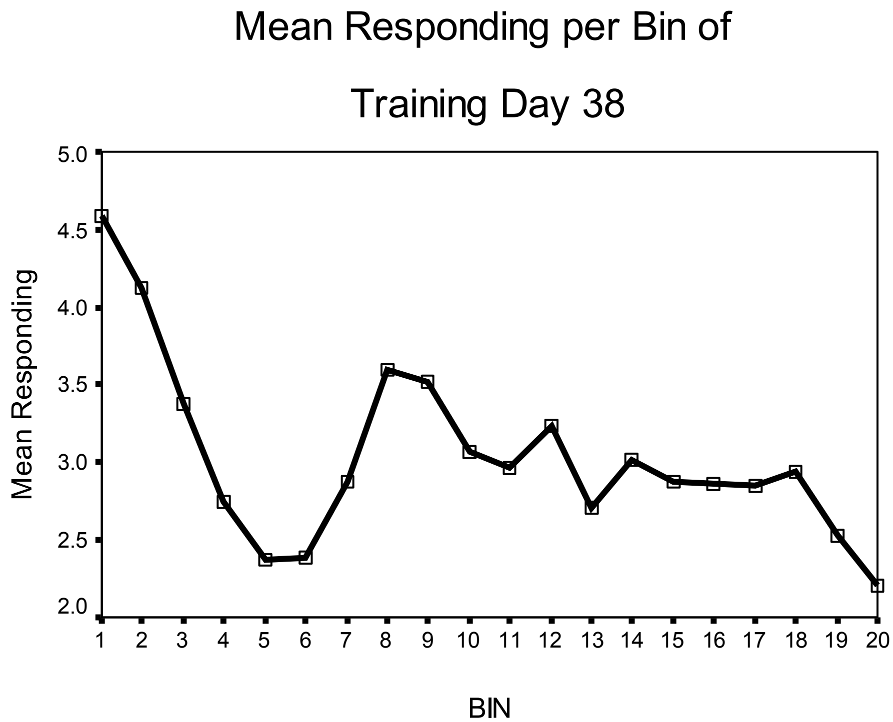


Figure 2. Mean responding during the last training session of a temporal discrimination task averaged across four probe trials. The x-axis refers to five s bins in which the CS was presented. Mean number of head entries is labeled on the y-axis.

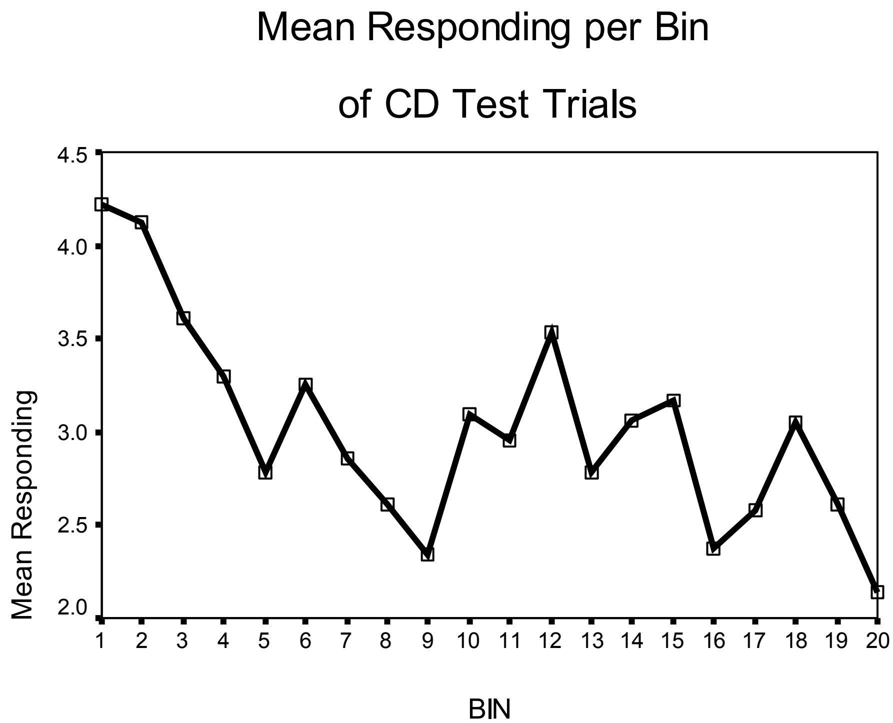


Figure 3. Mean responding per bin of CS when preceded by the compound CD.

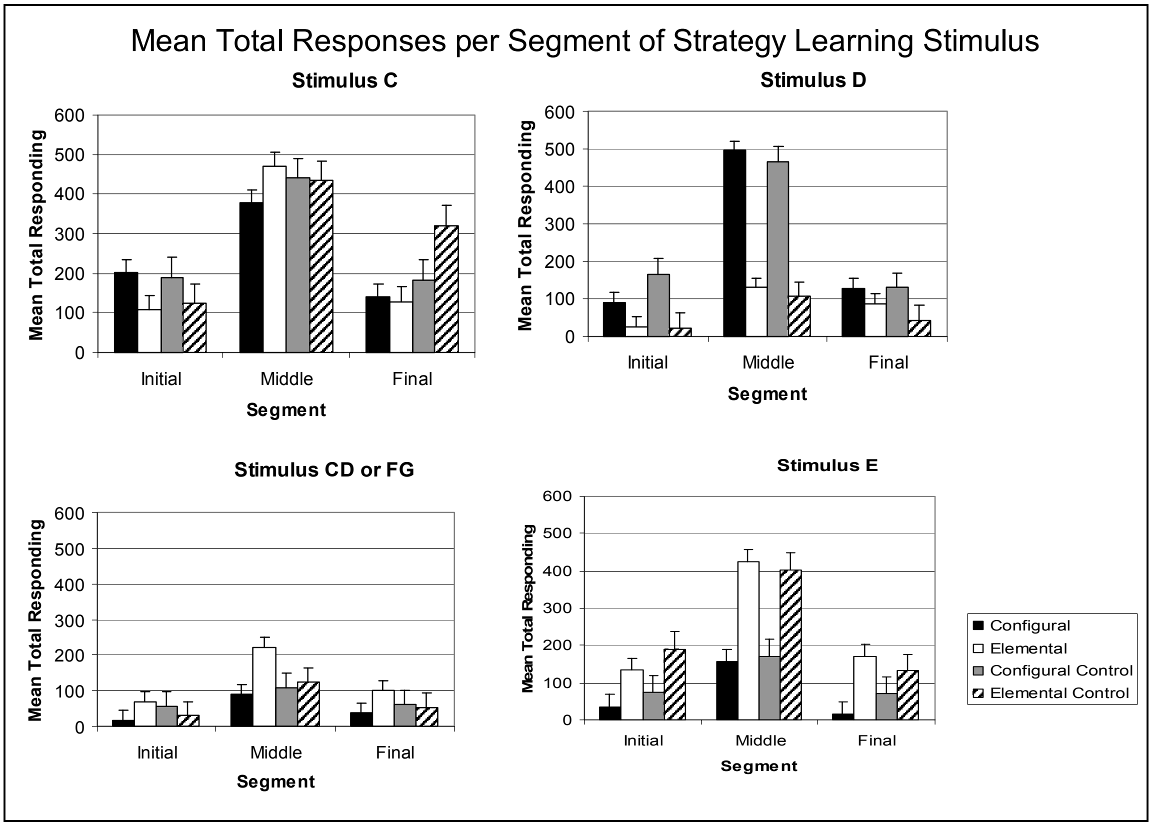


Figure 4. Results from the Strategy Learning Phase. The middle segment of stimulus C was reinforced for each of the four groups. The middle segment of stimulus D was reinforced only for the configural and configural control groups, and the middle segment of stimulus E was reinforced for the elemental and elemental control groups. Reinforcement was not delivered for any group in the trial labeled Stimulus CD. In this trial, the compound CD was presented without reinforcement to elemental and configural group, and FG was presented without reinforcement to both control groups.

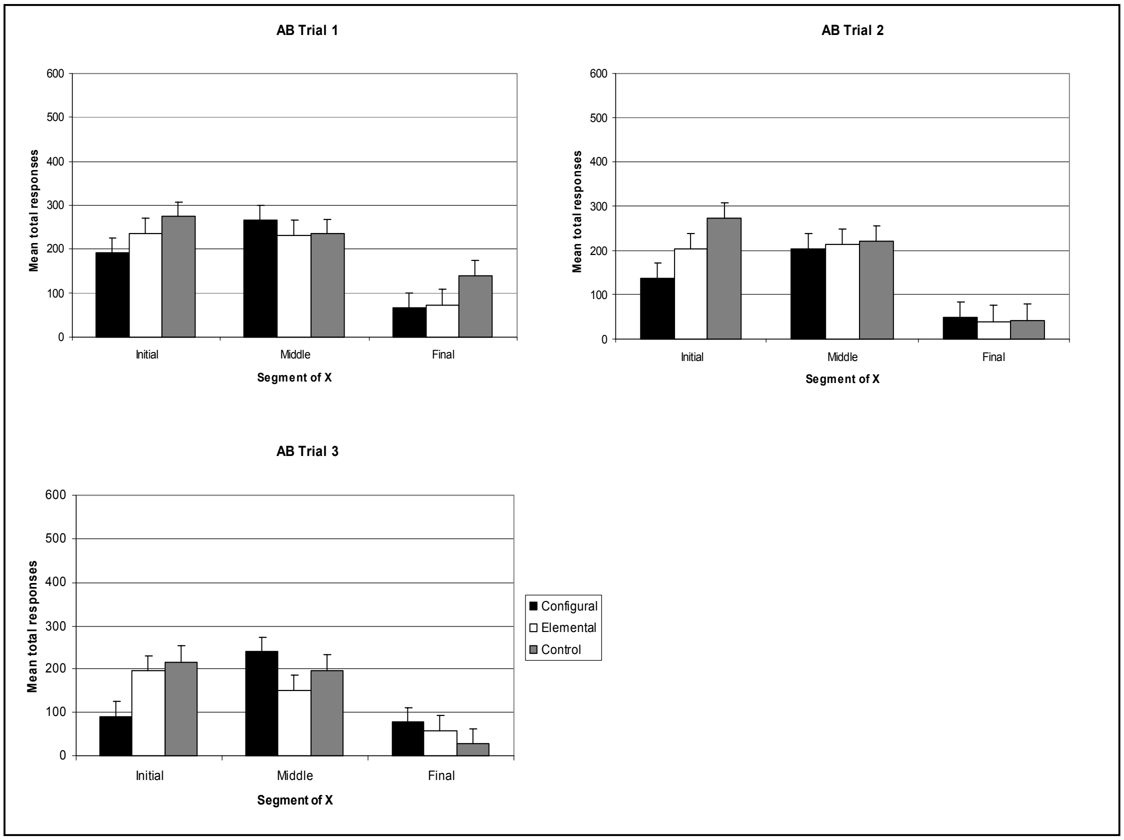


Figure 5. Mean total responding per segment of each AB→X test trial.

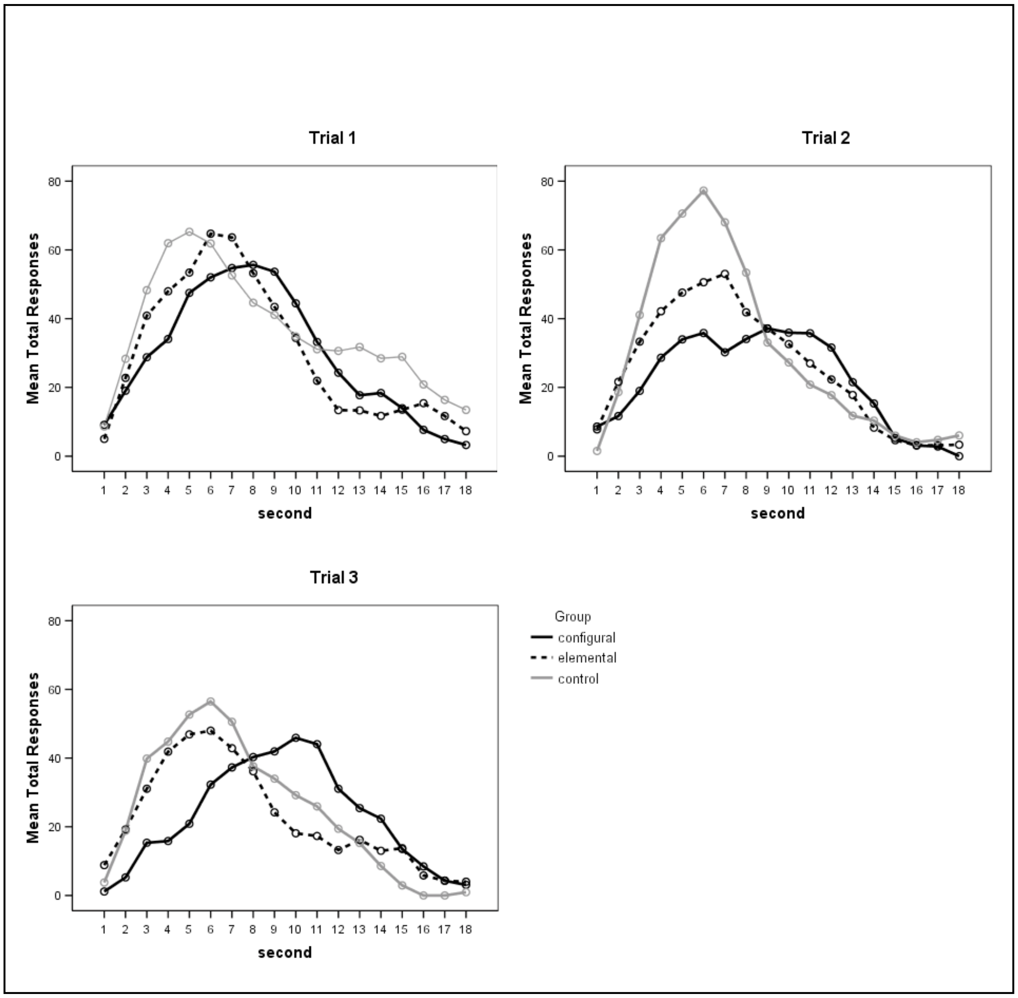


Figure 6. Mean total responding per second of each AB→X test trial

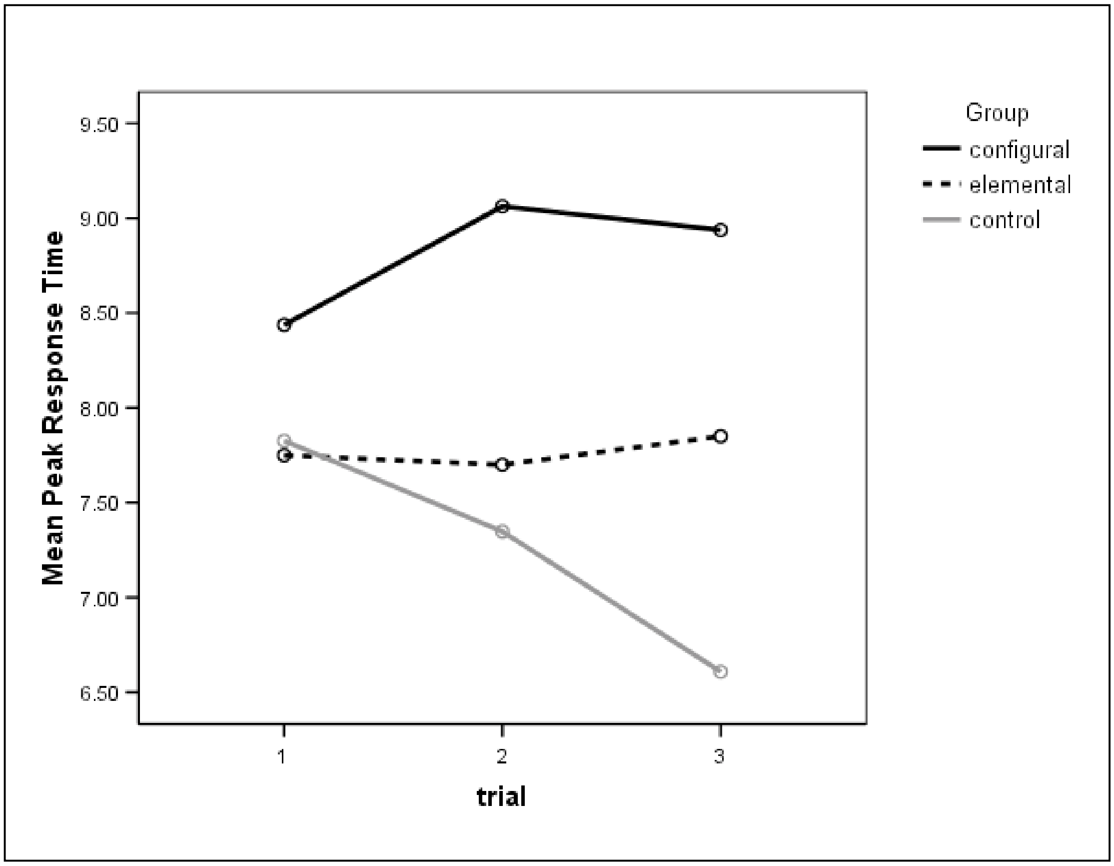


Figure 7. The mean time of peak responding of each group across the three test trials.

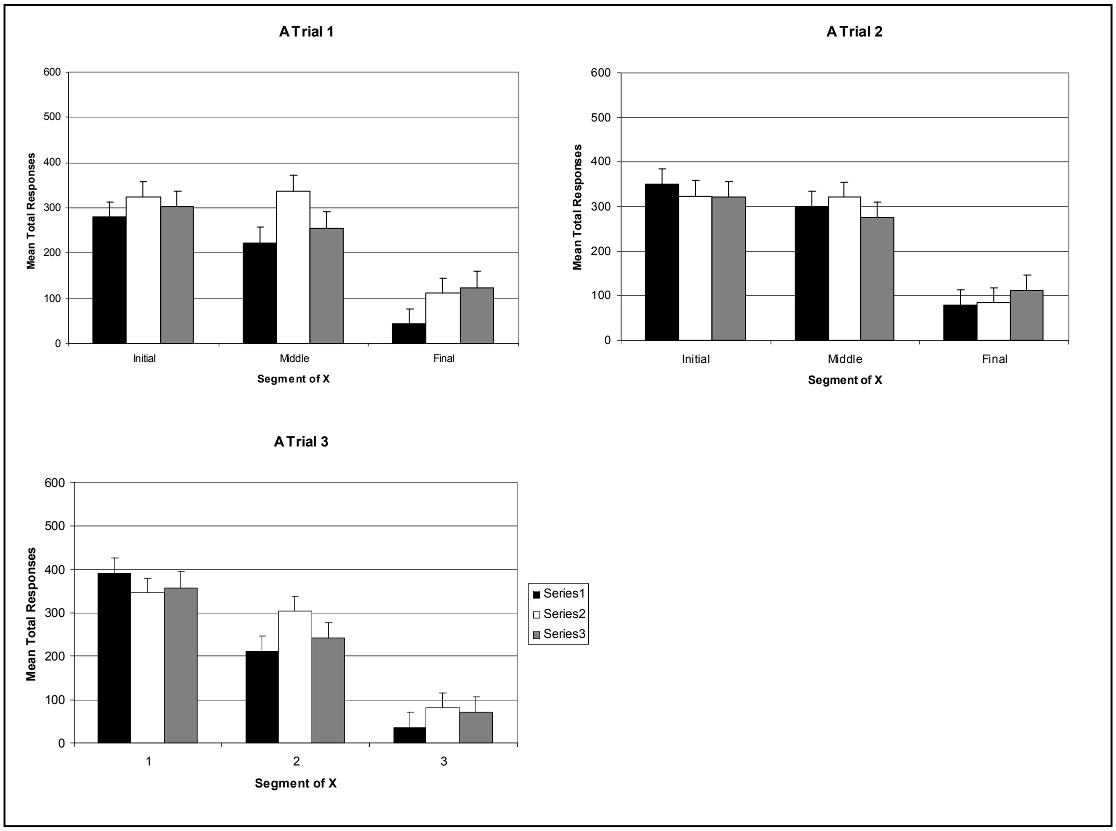


Figure 8. Mean total responding per segment of each A→X test trial.

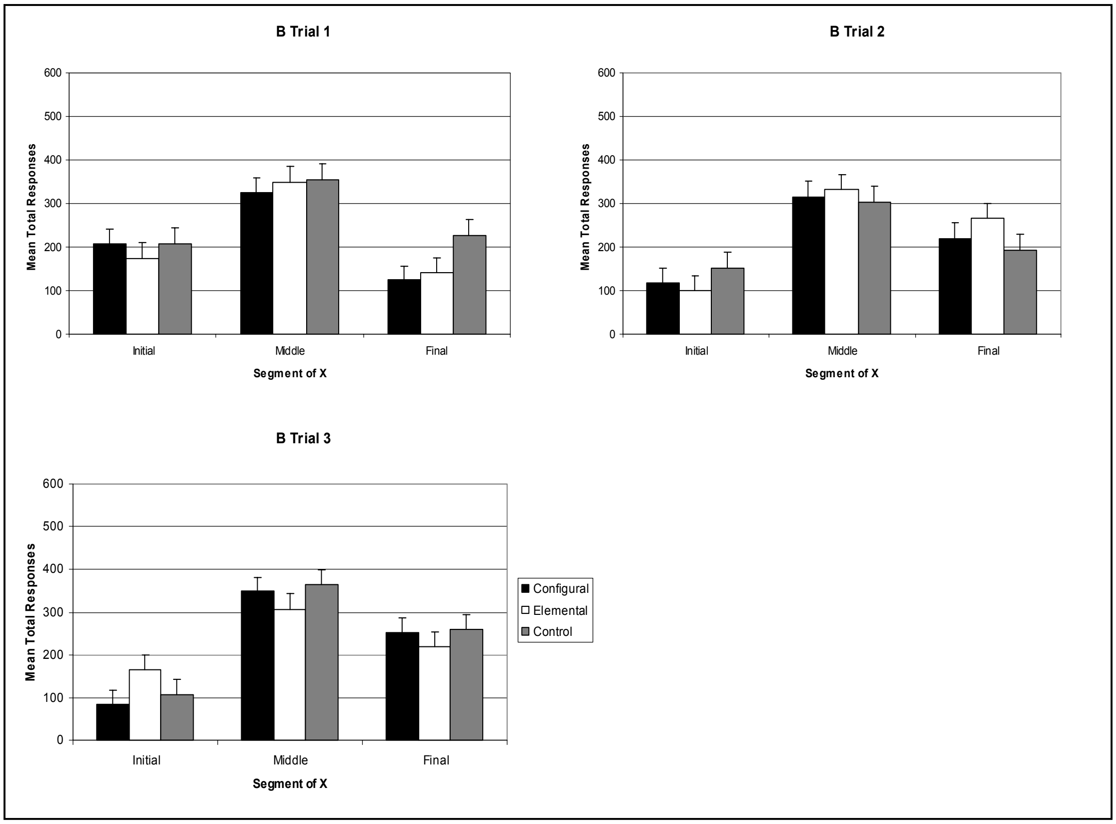


Figure 9. Mean total responding per segment of each B→X test trial.

Appendix C—Experimental Design Table

Group	Strategy Learning	Test	Discrimination Learning	Test
Configural	C	C	A ▶ X	AB ▶ X
	D	D	B ▶ X	A ▶ X
	CD	CD		B ▶ X
	E	E		
Elemental	C	C		
	D	D		
	CD	CD		
	E	E		
Configural Control	C	C		
	D	D		
	FG	FG		
	E	E		
Elemental Control	C	C		
	D	D		
	FG	FG		
	E	E		

Table 1. Description of experimental design. Light colored boxes represent 18 s duration of stimuli C, D, CD, E, and X. Dark colored boxes represent 6 s duration of the outcome stimulus. A, B, and AB were 3 s in duration. In the strategy learning phase, participants observed the relationship between single presentations of C, D, E, CD or FG cues and the outcome stimulus. Then, the participants were asked to respond if and when they expected the outcome to occur in relationship to the previously observed cues. In the discrimination learning phase, participants observed the relationship between both A and B and the outcome stimulus. Then they were asked to respond if and when the expected the outcome based on A, B and AB during the test task. The discrimination learning phase consisted of three cycles of the observation/test tasks.