Journal of Experimental Psychology:
Animal Behavior Processes
1987, Vol. 13, No. 1, 80–91

0097-7403/87/$00.75

Dissociation of Stimulus Compounds by Pigeons

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Short-term memory for compound visual stimuli in pigeons was investigated using a matching-to-sample (MTS) procedure. In the first experiment, a symbolic MTS procedure was used. Three birds were trained to match element samples, and 3 were trained to match compound samples. Birds in both training conditions then matched both element samples and a variety of compound samples differing in the spatial configuration of their elements. There was transfer of matching ability from element samples to compound samples, but not vice versa. This indicates that the compound-trained group did not learn to match the compound samples in terms of element matching rules but rather processed them as unitary events. In a second experiment, pigeons were trained to match either element or compound samples in a "true" MTS task (in which the test stimuli were physically identical to the element samples). Both of these groups were able to match elements and compounds in the transfer test. This indicates that exposure to the elements as test stimuli was sufficient to result in analytic processing of the compound samples. These findings show that at least some compound stimuli are represented in a unitary, nonanalytic fashion until the animal is exposed to the elements of the compound in isolation from the compound.

Most natural stimuli are compounds. That is, they are composed of multiple elements, each of which can be defined in terms of a dimension such as color or shape. Within the fields of cognitive and developmental psychology, many theorists claim that under a variety of conditions the perceptual and memorial processes responsible for the encoding and retention of compound stimuli operate on the compound as a whole, rather than the elements of the compound (e.g., Ceraso, 1985; Kemler, 1983; Kohler, 1947; Garner, 1974; Gibson, 1969; Shepp, 1983; Tighe & Tighe, 1978). In general, these theorists claim that compound stimuli are represented in either a unitary (nonanalytic) or elemental (analytic) fashion, depending on a number of factors.

Within the domain of animal learning, many theorists have assumed that associative strength is assigned to the elements of compound stimuli rather than to the compound as a whole (e.g., Mackintosh, 1975; Pearce & Hall, 1980; Rescorla & Wagner, 1972). This assumption requires that compound stimuli be processed analytically. Direct evidence for the notion that stimulus compounds can be processed in an analytic fashion by animals has come from work utilizing the matching-to-sample (MTS) paradigm. In this procedure, a hungry pigeon is presented with a large number of discrete trials in a three-key operant chamber. Each trial is initiated by a warning signal, typically achromatic illumination of the center key. A single peck to the warning signal results in presentation of a to-be-remembered stimulus (the sample). After a short exposure period, the sample is extinguished, and stimuli are presented on the two side keys (the test stimuli). One of the two test stimuli is designated as correct, with a peck to that stimulus being followed by food reinforcement.

Early work using this procedure to study compound stimulus processing compared performance on trials with element samples to performance on trials with compound samples (Maki & Leith, 1973; Maki & Leuin, 1972). Element samples were either one of two color values (e.g., red or blue) or lines presented in one of two orientations (vertical or horizontal). Tests on element trials always pitted a stimulus that was identical to the sample against the alternate value from the dimension represented by the sample. A typical element trial might consist of a red sample followed by a choice between red and blue, with a peck to the red test key being followed by food. Accuracy on element trials was compared with accuracy on compound trials, in which the sample consisted of both a color and a line orientation (e.g., vertical lines on a blue background). Tests following compound samples pitted two values from one dimension against each other (i.e., either red vs. blue *or* vertical vs. horizontal). The dimension tested on compound trials was unpredictable. The results of these experiments showed that accuracy on element trials was consistently higher than accuracy on compound trials. This difference between element and compound matching accuracy (subsequently referred to as the *element/compound difference*) has been the catalyst for a large amount of experimentation and theoretical debate.

The element/compound difference was interpreted as supporting the hypothesis that during presentation of a compound sample, the pigeon must divide a limited attentional capacity

The experiments reported in this article were submitted to the University of California, Berkeley, in partial fulfillment of the requirements for the degree of PhD. They were supported by National Science Foundation Grant BNS-8317577 to D. A. Riley.

I thank Donald A. Riley for his support during the course of this work and throughout my graduate career. Thanks also to the other members of my dissertation committee—Curtis Hardyck, Stephen Palmer, Seth Roberts, and John Watson—for valuable advice on the experiments and the manuscript.

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between the two dimensions contained in the sample and that as a result it encodes less information about either one of them than is possible during an element trial. This "shared-attention" hypothesis has two parts that should be separated for the present purposes. First, it assumes that the pigeon analyzes or "decomposes" the sample into its dimensional components and that these components serve as the functional units on which subsequent processes operate. Second, it proposes that because encoding information about two units requires a greater amount of attentional capacity than does encoding information about one unit, "information overload" occurs, and accuracy is lower following compound samples than following element samples (Riley, 1984).

The shared-attention explanation of the element/compound difference has been challenged by two alternative accounts, both of which reject the assumption of analytic compound processing. The "generalization decrement" hypothesis points to the fact that the element test stimuli are identical to the element samples, but differ from the compound samples (Cox & D'Amato, 1982; Maki, Riley, & Leith, 1976; Roberts & Grant, 1978). The element/compound difference is attributed to greater sample-to-test stimulus generalization when the sample is an element than when the sample is a compound. The "coding decrement" hypothesis attributes the element/compound difference to the typical procedure of training birds to match elements prior to the introduction of compound samples (Grant & MacDonald, 1986). The present experiments were designed to investigate the assumption of the shared-attention hypothesis that compound visual stimuli are processed in an analytic manner by pigeons. Knowledge of the conditions under which this assumption holds is important not only for understanding the determinants of compound MTS performance but also for developing a general understanding of the manner in which compound stimuli are perceived, encoded, and remembered by pigeons.

Recent MTS experiments indicate that stimulus compounds may be processed in an analytic manner under some conditions but in a unitary manner under other conditions. Lamb and Riley (1981) and Lamb (1982) investigated the role of the spatial configuration of the elements of compound stimuli on matching accuracy. They argued that compounds in which the two dimensional values are contained in the same "object" (i.e., the compound consists of lines that have both a particular orientation and are colored) are processed as unitary stimuli, rather than as two independent dimensional values. Lamb and Riley refer to such compounds as "Unified." Ceraso (1985) has made a similar argument using data from human subjects.

In addition to the configural properties of compound samples, there may be other factors that influence whether compounds are treated in an analytic or unitary fashion. In particular, it may be that many compounds are initially processed in a unitary fashion but come to be analyzed into their elements through experience. This idea is derived from the "perceptual learning" framework of Gibson (1969), who has proposed that the properties and dimensions of complex stimuli must be "abstracted" from the stimulus by a learning process that occurs when the subject is exposed to those features outside of the context of the compound. Gibson's basic notion has been supported by work indicating that young children tend to perceive compound stimuli in a unitary fashion, whereas older children are more likely to perceive them in terms of their elements (see Kemler, 1983; Shepp, 1983; Tighe & Tighe, 1978, for reviews).

The process by which representations of complex stimuli are transformed into representations of elements was labeled "dissociation" by William James (1890/1950). Such "dissociative" learning processes have been largely ignored in the study of associative learning, which focuses on the formation of *connections* between representations of stimuli rather than the *division* of complex representations into simpler units. However, several previous authors have argued that compound stimuli used in a variety of conditioning preparations may have or come to have properties that cannot be described as a simple combination of the properties of their elements (e.g., Gray & Lethbridge, 1976; Razran, 1971; Rescorla, 1973; D. Wickens, Nield, Tuber, & C. Wickens, 1970; see Kehoe & Gormezano, 1980, for a review). For example, Rescorla (1973) argued that a "unique stimulus" is formed by the combination of two elements. Tighe (1973) presented data from discrimination learning paradigms indicating that rats, pigeons, and turtles sometimes discriminate compound stimuli as wholes rather than in terms of their elements even when the elements are valid predictors of reinforcement. Finally, a recent analysis of flavor aversion learning suggests that flavor compounds initially may gain and lose associative strength as single, unitary stimuli and that the elements may acquire the ability to gain and lose associative strength as independent units only after rats are given exposure to the elements outside of the context of the compound (Freberg, 1979; Rescorla, 1981).

These findings raise the possibility that the compound visual stimuli used in MTS are processed in a unitary manner until pigeons are given experience with the elements that comprise the compounds. Exposure to the elements of compound samples might be expected to result in dissociation of the compound into its elements, resulting in the compound's being subsequently processed in terms of its elements rather than as a single, unitary stimulus. Under normal conditions, this occurs because of presentation of the elements as samples and/or test stimuli. Thus, the analytic processing of compound stimuli assumed by the shared-attention hypothesis may depend not only on the configural properties of the compound but also on the previous experience of the subject with the compounds and/or with the elements that compose them. The present experiments were designed to investigate this possibility.

Experiment 1

The first experiment used a *symbolic* matching procedure. In symbolic MTS, the sample and test stimuli bear no physical resemblance to each other. Rather, there is an arbitrary mapping between each sample and a test stimulus. The symbolic procedure was used because subjects are not exposed to the element stimuli during test stimulus presentation, as is the case when true MTS is used. The notion that the elements of compound stimuli are processed independently only when the subject has had previous experience with the elements in isolation was tested by varying the training conditions to which the birds were exposed.

Three pigeons were first trained to match element samples

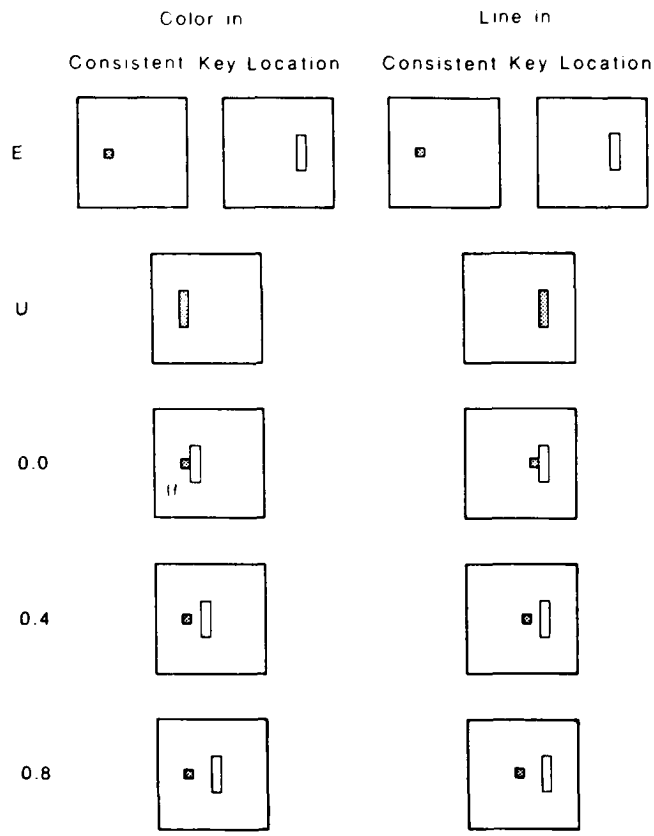

Figure 1. Representative samples from the two sample sets used in the transfer tests of Experiments 1 and 2. (The border surrounding each stimulus represents the sample key, and the speckled area represents colored areas (red or green). E = element; U = Unified compound; 0.0, 0.4, and 0.8 denote element separation in cm. Drawings are to scale.)

and then tested with both element samples and a variety of compound samples. A second group of 3 birds was first trained to match one set of compound samples prior to being tested with elements and compounds. Thus, the latter group was never exposed to the elements of the compound stimuli either as samples or as test stimuli. According to the notion that such exposure is important for allowing analytic processing of compound stimuli, birds trained with compounds should not learn to match the compound samples on the basis of their elements and hence should be unable to match element samples in the transfer test. Birds trained with element samples, on the other hand, should analyze the compound samples presented in the test into elements, and match them in terms of those elements. If compound samples are processed analytically regardless of the experience of the bird, then transfer both from element training to compound matching and transfer from compound training to element matching would be expected.

The transfer test included element samples as well as several different types of compound samples, differing in the spatial configuration of their elements. Presentation of a variety of compound samples in the transfer test served as a control for any disruption of matching ability due simply to the introduction of novel stimuli as samples. The Unified compound (see below) was particularly important in this respect because of its relative dissimilarity to the compound samples used during training.[1]

Method

Subjects. The subjects were 6 pigeons of mixed breed obtained from a local supplier. They had previously participated in autoshaping experiments involving photographs of grain as stimuli. They were maintained at 80%–85% of their free-feeding weights and had access to water and grit in their home cages.

Apparatus. The experiment was conducted in a three-key operant chamber measuring 37.7 cm in height, 31.2 cm in depth, and 36.4 cm across the front and back walls. The inside of the chamber was painted flat black, with the exception of one Plexiglas side wall, which served as the door. The keys (BRS/LVE Model 121-16) were 23.4 cm above the wire mesh floor. The center key measured 3.3 cm square. The round side keys were 2.6 cm in diameter, and their distance from the center key (center to center) was 10.4 cm. The food hopper (BRS/LVE Model 1110) opening, through which the subjects received mixed grain reinforcement, was 6.5 cm square and 15.6 cm below the center key. Stimuli were back-projected onto the keys by Kodak slide projectors (Model E-2) through a series of lenses and beam splitters. The onset and offset of stimuli on the center key was accomplished with high-speed shutters (Uniblitz Model 214LOAOT5H), with rise and fall times of 1.3 ms and 2.3 ms, respectively. Stimuli on the side keys were presented using Uniblitz Model 26LOA3X5 shutters, with rise and fall times of 1.6 ms and 2.6 ms, respectively. The apparatus was in a windowless room that had been painted flat black.

Stimuli. Each bird was presented with samples from one of two stimulus sets. In both sets, color element samples consisted of a 0.2-cm square that was either red (R; Kodak Wratten filter No. 16) or green (G; Kodak Wratten filter No. 58). It was 0.7 cm from the left edge of the key and centered vertically. Line elements consisted of an achromatic line (0.2 cm × 1.0 cm) that was either vertical (V) or horizontal (H). The center of the line was 0.7 cm from the right edge of the key. Four different spatially configured types of compound samples were used. "Unified" samples consisted of a colored (R or G) bar, the same size as the line elements and either vertical or horizontal. Three types of spatially separated compound samples consisted of both the color element and the line orientation element. The three types differed in the spatial separation between the elements (measured edge to edge). The elements were separated by either 0, 0.4, or 0.8 cm. Figure 1 shows examples of stimuli of each type in the two sample sets. In the sample set shown in the left column of Figure 1, spatial separation was manipulated by varying the location of the line element on the key. In the sample set shown in the right column, the location of the color element was varied.[2]

Four different test stimuli were used. They can be described as two pairs of forms, one pair being small, filled figures and the other being large, open figures. Each pair included a circle and a diamond. The larger pair consisted of black lines (0.1 cm thick) on an achromatic background. The circle was 2.0 cm in diameter, while the sides of the

[1] This particular sample set was used so that the results of the present experiment could be directly compared with those of others in which the same samples were used (Lamb, 1982; Cook, Riley, & Brown, 1986). The term *Unified* follows the nomenclature used by Lamb and Riley (1981) and refers to the spatial arrangement of the sample elements. Whether or not Unified samples are processed in a unitary fashion is an empirical question.

[2] Two different sample sets were used in order to conform to the conditions previously used by Cook et al. (1986). This manipulation will not be discussed in the present article.

BIRD	TRAINING SAMPLES	CONSISTENT LOCATION	SAMPLE-TO-TEST MAPPING			
			Red	Green	Vertical	Horizontal
61	Element	Color	○	◇	●	◆
2	Element	Color	◆	●	◇	○
32	Element	Line	◇	○	●	◆
71	Compound	Color	◇	○	●	◆
3	Compound	Line	○	◇	●	◆
40	Compound	Line	◆	●	◇	○

Figure 2. Subject assignments in Experiment 1. (The column labeled *training samples* indicates whether the subject was trained on the elements or on the 0.4 compounds. The column labeled *consistent location* indicates whether the spatial location of the color element or the line element was invariant. The test stimulus designated as correct for each element is also shown.)

diamond were 2.0 cm in length. The smaller pair were solid black and were also on an achromatic background. The circle was 1.1 cm in diameter, and the diamond had sides that were 1.1 cm in length. These stimuli were presented in the center of the round test keys.

Design. Each bird was assigned to a training-sample-type condition and a sample-set condition, and was assigned a set of sample-to-test mappings. These assignments are shown in Figure 2. The column labeled *training samples* indicates whether the birds were trained with element samples or with the 0.4 compounds (i.e., the compounds with elements separated by 0.4 cm). Three birds were trained using element samples (Birds 61, 2, and 32), and 3 birds were trained using the 0.4 compounds (Birds 71, 3, and 40). The column labeled *consistent location* indicates which of the two sample sets was used (color or line element presented in a consistent key location during the transfer test). Three birds received the set in which the location of color remained constant (Nos. 61, 2, and 71) while three received the alternate set (Nos. 32, 3, and 40). The right-hand portion of Figure 2 shows which test stimulus was designated as correct following the presentation of each dimensional value. The assignments were such that pairs of birds receiving different sample sets were given the same sample-to-test mappings (Nos. 61 & 3, 71 & 32, and 2 & 40). The small, filled symbols were always associated with the values of one dimension while the large, open symbols were mapped onto the alternate dimension.

Training. During training, each bird learned to match four samples: either the four elements or the four compounds with elements separated by 0.4 cm. Initially, an autoshaping procedure was used in which an achromatic warning signal was first presented on the center key, followed by one of the four training samples on the center key, followed by a test stimulus (one defined as correct following the sample), and finally followed by food. Pecks to any of these stimuli advanced the trial to the next stage. After consistent responding was produced, the birds were exposed to the matching-to-sample procedure.

Each trial was initiated by achromatic illumination of the center key. A single peck to this warning signal resulted in its replacement by one of the four training samples. Twenty pecks to the sample were required (during the first few sessions, this sample response requirement was increased from 1 peck to the terminal value of 20 pecks). The sample stimulus was then turned off, and two test stimuli were presented on the side keys. For birds in the element training sample condition, the test stimuli appropriate for the dimension represented by the sample were presented. For birds in the compound training sample condition, the dimension tested was unpredictable from trial to trial. A peck to the test stimulus that was designated correct for the sample presented was followed by 3 s access to mixed grain in the illuminated hopper. A 10 s intertrial interval (ITI) separated trials. Failure to peck the warning signal or to peck one of the test stimuli within 10 s resulted in re-presentation of the trial.

Trials were presented in blocks of 16. Each block contained equal numbers of each trial type, with trial type defined by the dimensional value(s) contained in the sample, the dimension tested, and the location (right or left test key) of the correct test stimulus. Sessions consisted of five blocks, preceded by a warm-up block of eight trials, the data from which are not included in the results.

Phase 0: During the first phase of training, all four training samples were presented 20 times in each session. During this time, a number of procedures were used in an attempt to improve matching accuracy. These included increasing the ITI to 15 s, a correction procedure in which each trial was repeated until a correct response occurred, and a

Table 1
Examples of Trial Types During Training in Experiment 1

Element training (Bird 61)		Compound training (Bird 3)	
Sample	Test	Sample	Test
R	LC+ vs. LD−	RV	LC+ vs. LD−
G	LC− vs. LD+	RV	SC+ vs. SD−
V	SC+ vs. SD−	GH	LC− vs. LD+
H	SC− vs. SD+	GH	SC− vs. SD+
		RH	LC+ vs. LD−
		RH	SC− vs. SD+
		GV	LC− vs. LD+
		GV	SC+ vs. SD−

Note. R = red; G = green; V = vertical; H = horizontal; LC = large circle; LD = large diamond; SC = small circle; SD = small diamond; + = correct; − = incorrect. Positions of the test stimuli (left vs. right) were counterbalanced within each trial type. The two cases illustrated correspond to the same set of element matching rules.

correction procedure in which the correct test stimulus remained available following an incorrect response (and was reinforced when pecked). However, because little or no evidence of learning was obtained during this training phase (see Results), it was abandoned.

Phase 1: The birds were then trained on one subset of the training samples at a time. Birds in the element training condition were first trained to match colors, with each of the two values being presented 40 trials per session. Birds in the compound training condition were first trained to match the RV and GH compounds, with each being presented 40 trials per session and each dimension being tested on half of those trials. Training continued until a criterion of 7 out of 10 consecutive sessions with accuracy above 80% was reached.

Phase 2: Subjects were then trained on the other two training samples (V & H for element-trained birds; RH & GV for compound-trained birds) until the same criterion was reached.

Phase 3: Subjects were then given alternate sessions of training on the two subsets of the training samples until accuracy was above 80% for 5 days on each subset.

Phase 4: In the final phase of training, subjects received sessions containing equal numbers of all four training samples until accuracy was above 80% for 10 sessions. Table 1 illustrates the element and compound matching tasks learned by birds in the two groups with an example of each.

Transfer test. Following successful completion of training, 10 sessions were given in which the entire set of samples was used (either the set in which the key location of the color element was fixed or the set in which the location of the line element was fixed for each bird). The sessions were divided into five blocks of 16 trials. Within each block, only one sample type (elements, Unified compounds, or one of the three configurations of separated compounds) was presented. The blocks were presented in a random order during each session. Due to experimenter error, Bird 40 was given only nine sessions during this transfer phase.

Results

Training. The first training procedure, in which the birds were given all four training samples, proved to be ineffectual. After a mean of 64 sessions, only 1 bird (No. 32) was matching above chance levels.

The number of sessions required for each of the following four phases of training to be completed for each bird is shown in Table 2. Birds in the compound training condition (Nos. 71, 3, and 40) appear to have reached the training criterion faster than those in the element training condition (Nos. 61, 2, and 32). Also worth noting is the transfer of matching accuracy from the first subset of training samples (RV and GH) to the second subset (RH and GV) during training Phase 2 among the 3 birds in the compound training condition. All 3 of these subjects matched the second training subset at very high levels of accuracy during the first session of Phase 2 of training (91%, 90%, and 76% correct for Birds 71, 3, and 40, respectively).

Transfer test. The results of the transfer test are shown in Figure 3. The 3 birds in the element training condition demonstrated successful transfer of matching accuracy to all compound stimuli. The matching accuracy of all 3 birds trained with element samples was above 50% correct on each sample type (elements, Unified, and all three levels of spatially separated compounds) during all 10 sessions of the transfer test. The 3 birds in the compound training condition, however, showed transfer to the other compounds, but no transfer to the element samples. Their matching accuracy was above 50% on all four compound types during all 10 sessions of the transfer test. Their accuracy on element trials, however, was exactly 50% during all 10 sessions of the transfer test, with the exception of Bird 40, who attained an accuracy level of 62.5% during Sessions 4 and 7 of the transfer test. The fact that accuracy levels were exactly 50% during all but two of these 29 transfer sessions indicates that each bird responded to the same test key following every element sample (i.e., the birds responded on the basis of a test key preference). This can be inferred because of the nature of the counterbalancing procedure used, although which of the two side keys was pecked was not actually recorded.

A Training Condition (trained with element samples or compound samples) × Sample Type (element, Unified compounds, etc.) × Dimension (color vs. line) analysis of variance (ANOVA) revealed a significant effect of sample type, $F(4, 16) = 3.5$, $p < .05$, and interaction between training condition and sample type, $F(4, 16) = 15.6$, $p < .001$, and a three-way interaction among training condition, sample type, and dimension, $F(4, 16) = 4.7$, $p < .025$, with no other effects reaching the significance level of $p < .05$. Of particular interest is the interaction between sample type and training condition, which was produced by the asymmetrical transfer effect described above.

To examine the effect of sample type on the matching accu-

Table 2
Sessions Taken To Complete Training Phases in Experiment 1

	Phase				
Bird	1[a]	2[b]	3[c]	4[d]	Total
61	43	42	34	11	130
2	39	73	65	15	192
32	16	24	12	18	70
71	17	7	11	10	45
3	25	7	12	12	56
40	15	11	11	13	50

[a] Training on colors or red–vertical and green–horizontal. [b] Training on lines or red–horizontal and green–vertical. [c] Sessions alternate between two training subsets. [d] All four training samples.

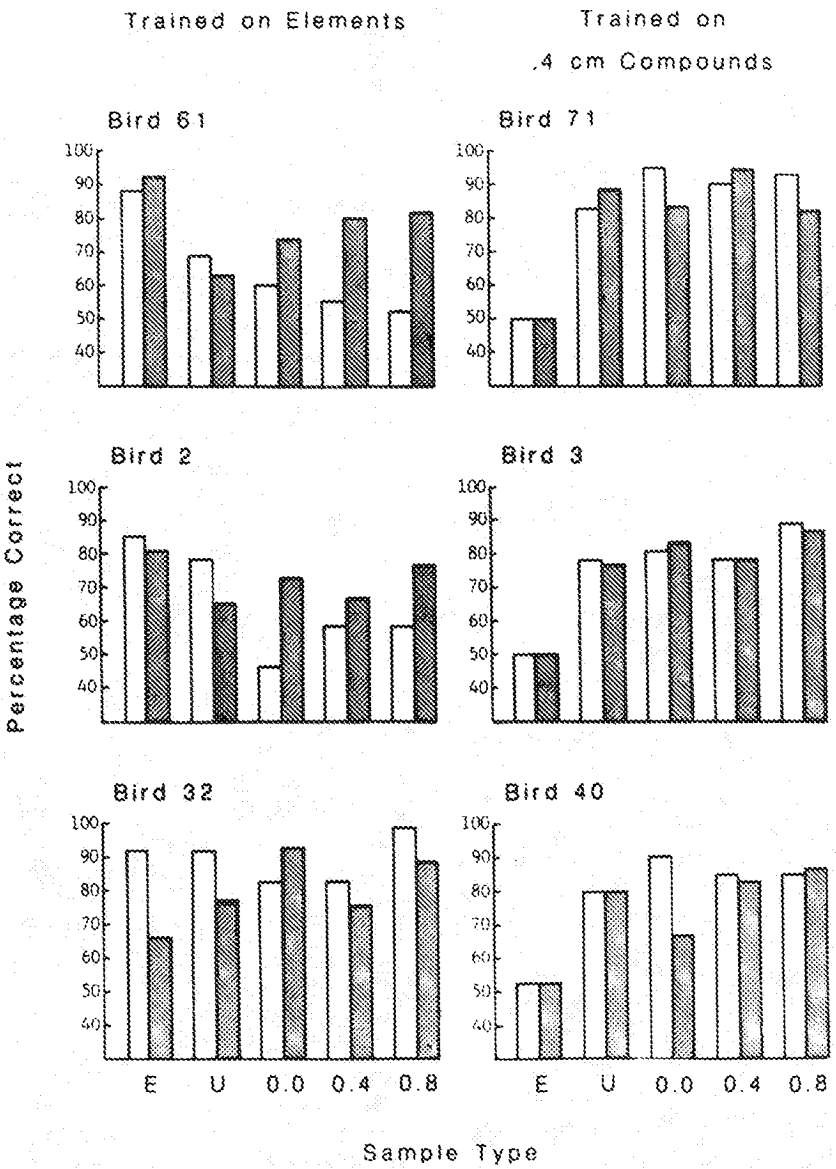

Figure 3. Matching accuracy during the 10-session transfer test of Experiment 1. (The open bar of each pair shows percentage correct on color tests, while the speckled bar shows percentage correct on line orientation tests. (E = element; U = Unified compound; 0.0 = compound with 0.0-cm spatial separation, etc.)

racy of individual birds, ANOVAS (Sample Type × Dimension) were performed on the data of each subject. The effect of dimension and interaction between dimension and sample type are of little theoretical interest and were inconsistent from bird to bird and hence will not be reported here (they can be found in Brown, 1985). The analyses revealed a significant effect of sample type for all 6 birds, $Fs(4, 90) = 11.7, 6.4, 2.6, 85.8$, and 6.4 for Birds 61, 2, 32, 71, and 3, respectively, $F(4, 80) = 14.1$ for Bird 40 (all $ps < .05$). In order to examine the locus of the effect of sample type, all possible pairwise comparisons of sample types were performed on the accuracy of each bird using F tests. These tests compared the mean of performance on color tests and line tests in order to assess the the total amount of information available to the subject at the time of the test (cf. Lamb & Riley, 1981, p. 50). The results of this analysis can be summarized as follows: There was, in general, a significant difference between accuracy following element samples and accuracy following compound samples (of each type) for all birds except Bird 32. There were no significant differences in accuracy among the various compound types. The difference in accuracy following elements and compounds was due to better performance on elements than on compounds among the birds trained on elements and to a lack of transfer of matching ability to the elements among the birds trained on the compounds.

Discussion

The result of major interest in the present experiment is the asymmetrical transfer of matching ability between element and

compound samples, depending on whether the training set consisted of elements or compounds. Pigeons trained with element samples showed immediate transfer of matching ability to compound samples. Birds trained with compound samples, on the other hand, showed no transfer whatsoever to the element samples, although they matched novel compound samples at high levels during the transfer phase.

The significant transfer found in the element training group implies that these birds decomposed the compound samples into their dimensional components and matched them on the basis of those elements. The birds trained in the compound task, however, must have learned to match the compounds in a manner other than in terms of elements, because they were unable to match the elements when presented with them. The concept of "matching rules" (Carter & Werner, 1978) is useful in describing this notion. Matching rules are "if . . . , then . . ." statements that describe the associations between the sample and test stimuli. Birds in the element training condition apparently learned rules of the form "If the sample was red, then peck the large circle." That is, they learned a set of four matching rules, each of which corresponds to an element sample. Acquisition of such element-based rules explains the immediate and high level of element-to-compound transfer, if birds processed the compounds in terms of elements.

The contingencies of reinforcement operating for the birds in the compound-training condition also appear to encourage the acquisition of element-based matching rules. Consider the contingencies operating during training for Bird 3 (see Table 1). The only response that was *consistently* reinforced following compounds containing red was a peck to the large circle. Thus, if the compound stimuli had been processed analytically during training, there should have been a tendency to peck the large circle when a red element was presented in the transfer test. Thus, the lack of element matching ability following compound training indicates that birds in this group did not match the compounds in terms of their elements. Instead, each compound apparently served as a singular effective stimulus (i.e., it was processed in a unitary fashion). Thus, two different sample-specific matching rules were learned for each training sample. Bird 3, for example, learned "If the sample was red–vertical, then peck large circle (if the choice is between large diamond and large circle)" and "If the sample was red–vertical, then peck small circle (if the choice is between small circle and small diamond)." A corresponding set of two rules was learned for each of the other three samples. Such rules would not allow successful matching of element samples during the transfer test.

A priori, the task learned by the birds in the compound training condition seems to be more complex than that learned by the birds in the element training condition, regardless of the form of the matching rules learned by the compound-trained birds. If sample-specific rules are learned, then a total of eight rules must be learned by the compound birds as opposed to only four by the element birds. Likewise, acquisition of element rules during compound training would involve contingencies associated with multiple compound samples (See Table 1). Thus, it appears that the compound matching task should be more difficult to acquire than the element matching task. However, the training data shown in Table 2 indicate the opposite: The compound task was acquired more quickly than the element task. This is largely due to the fact that all three compound-trained birds matched the second subset of training samples (RH & GV; Phase 2 in Table 2) immediately upon exposure to them. This fact is particularly striking because it is not at all clear how the matching ability acquired during Phase 1 of training could allow matching of the second subset of compounds presented during Phase 2. Neither an elemental version of the matching rules learned in Phase 1 nor a multiple sample-specific matching rule account allows for the sample-to-test mappings of the second training subset to be derived from the first. Thus, the explanation for this transfer is not clear. One possibility is the exposure to the contingencies associated with the second training subset during the unsuccessful Phase 0 of training. It should be emphasized, however, that no evidence of above-chance accuracy was found during this phase among the birds in the compound training condition. Furthermore, it is not clear why Phase 0 of training would allow birds trained with compounds to match the second subset of training samples but not produce a similar effect among the birds trained with element samples.

Experiment 2

In the first experiment we found that pigeons trained in a symbolic MTS task with element samples were subsequently able to match compound samples, whereas pigeons trained with compound samples were not able to match element samples. The second experiment was designed to examine the difference between the training conditions that resulted in the asymmetrical transfer effect. The intended difference between the training conditions was that the element-trained birds, but not the compound-trained birds, were exposed to the elements of the compounds prior to matching compound samples. As argued above, this exposure could have allowed them to decompose the compound samples into their dimensional components and to match them on that basis. Birds trained with the compound samples, on the other hand, had never been exposed to the elements in isolation from the compounds. The notions of Gibson (1969) suggest that such exposure to the elements would result in dissociation of a compound stimulus into its constituent elements.

However, there were other differences between the element and compound matching tasks that were learned by birds in the two groups. During an element sample, for example, the upcoming test stimuli were determined by the sample, whereas either of two pairs of test stimuli followed a compound sample (i.e., the upcoming test was predictable during element samples but not during compound samples). A second difference was that birds trained on elements were shown only two of the four test stimuli during Phases 1 and 2 of training. Birds trained on compounds, however, received both sets of test stimuli during every session. Third, each element matching rule was given by the contingencies operating during individual trial types for element-trained birds. In the case of compound training, however, element rules were determined jointly by the contingencies operating during multiple compound trial types. These differences between element and compound training were con-

founded with the difference in element exposure in Experiment 1.

The hypothesis that the difference in element exposure was critical in producing the asymmetrical transfer effect was tested in the present experiment by using a "true" (nonsymbolic) MTS procedure, in which the test stimuli are physically identical to the element samples. By use of this procedure, birds could be trained on the compound task while being exposed to the element stimuli in the form of test stimuli. Birds in two different training conditions were compared. Two birds were trained in a true matching task, using element samples. The training procedure was identical to that used in Experiment 1 except that the test stimuli were colors and lines rather than the form stimuli used in the symbolic procedure of Experiment 1. After criterial accuracy on the elements was attained, a transfer test was conducted using the same sample set as in Experiment 1. The procedure used with this group is very similar to that used in many other compound MTS experiments, and it was anticipated that these birds would show a high degree of transfer, just as the birds in previous experiments have done. A second pair of birds was trained using the same compound samples as used to train the birds in the compound training condition of Experiment 1.

The question of interest was whether the same asymmetrical transfer effect would occur in the present "true" matching procedure as was found using the symbolic procedure. The only difference between the procedures of Experiment 1 and of the present experiment was that in the present experiment the correct test stimulus corresponded to an element of the sample, whereas in the symbolic procedure it did not. (There was one exception to this: In the present experiment the unsuccessful Phase 0 of training used in Experiment 1 was not used.) If the asymmetrical transfer found in Experiment 1 was due to something other than the difference in element exposure, then the same effect should be found in the present experiment. If, however, the asymmetrical transfer was due to the difference in exposure to the elements, then birds trained with compound samples in the present experiment should show transfer of performance to the element samples because of their exposure to elements in the form of test stimuli.

Method

Subjects and apparatus. The subjects were 4 pigeons that had participated in the same autoshaping experiment as the birds used in Experiment 1. The apparatus was the same as that used in Experiment 1.

Procedure. The design and procedure were very similar to those of Experiment 1, with the major exception that the test stimuli were identical to the element samples. They were presented in the center of the round side keys. The correct test stimulus on each trial was the one which was identical to the presented sample (element trials) or to an elemental component of the sample (compound trials). Two birds (Nos. 52 & 67) were trained using element samples before being transferred to the entire sample set, while two birds (Nos. 611 & 69) were trained on the compounds separated by 0.4 cm before being transferred. One bird in each of these two training conditions (Nos. 52 & 611) matched samples from the sample set in which the location of the color element remained fixed. A second bird in each of the training conditions (Nos. 67 & 69) matched samples from the set in which the location of the line orientation element remained fixed.

Table 3
Sessions Taken To Complete Training Phases in Experiment 2

	Phase				
Bird	1[a]	2[b]	3[c]	4[d]	Total
52	19	46	12	10	87
67	24	27	14	10	75
611	24	22	48	31	125
69	34	17	19	10	80

[a] Training on colors or red–vertical and green–horizontal. [b] Training on lines or red–horizontal and green–vertical. [c] Sessions alternate between two training subsets. [d] All four training samples.

Initial training consisted of the same autoshaping procedure used in Experiment 1. Birds in the element training condition were then trained to match colors, while birds in the compound training condition were trained to match the RV and GH compounds in the same manner and to the same criterion as in Experiment 1 (Phase 1). Training continued in the same manner as in Experiment 1 (Phases 2, 3, and 4). Thus, the training regimen was identical to that used in Experiment 1 except that the initial, unsuccessful training procedure used in that experiment (Phase 0) was not used. The structure of trials and sessions was identical to that used in Experiment 1.

A transfer phase lasting 10 sessions was then conducted as in Experiment 1. These sessions included samples of all five types (element, Unified compounds, and compounds in which the elements were separated by 0.0, 0.4, or 0.8 cm).

Results

Training. The number of sessions required for each of the four training phases to be completed by each bird is shown in Table 3. Unlike in Experiment 1, the compound task was not acquired more quickly than the element task nor was there immediate transfer of matching accuracy from training Phase 1 to training Phase 2.

Transfer test. The results of the transfer test are shown in Figure 4. Transfer of matching ability was obtained in both the element-trained birds and the compound-trained birds. Each of the 4 birds matched samples of each type (element, Unified, and the three levels of spatial separation) above 50% on every session of the transfer test.

A Group (trained with element samples vs. trained with compound samples) × Sample Type × Dimension ANOVA revealed a significant effect of sample type, $F(4, 8) = 5.4$, $p < .025$, and an interaction between dimension and sample type, $F(4, 8) = 5.2$, $p < .025$, with no other effects being significant.

All 4 subjects demonstrated a significant effect of sample type, $Fs(4, 90) = 5.4$, 12.5, 2.8, and 3.4 for Birds 52, 67, 611, and 69, respectively (all $ps < .05$). The results of pairwise comparisons of accuracy on the various sample types indicated that both birds trained with element samples matched elements more accurately than each of the various compound samples during the transfer test. Pairwise comparisons performed on the data of the compound-trained birds revealed no element/compound differences.

Discussion

The result of primary interest in the present experiment is that both birds trained using compound samples showed trans-

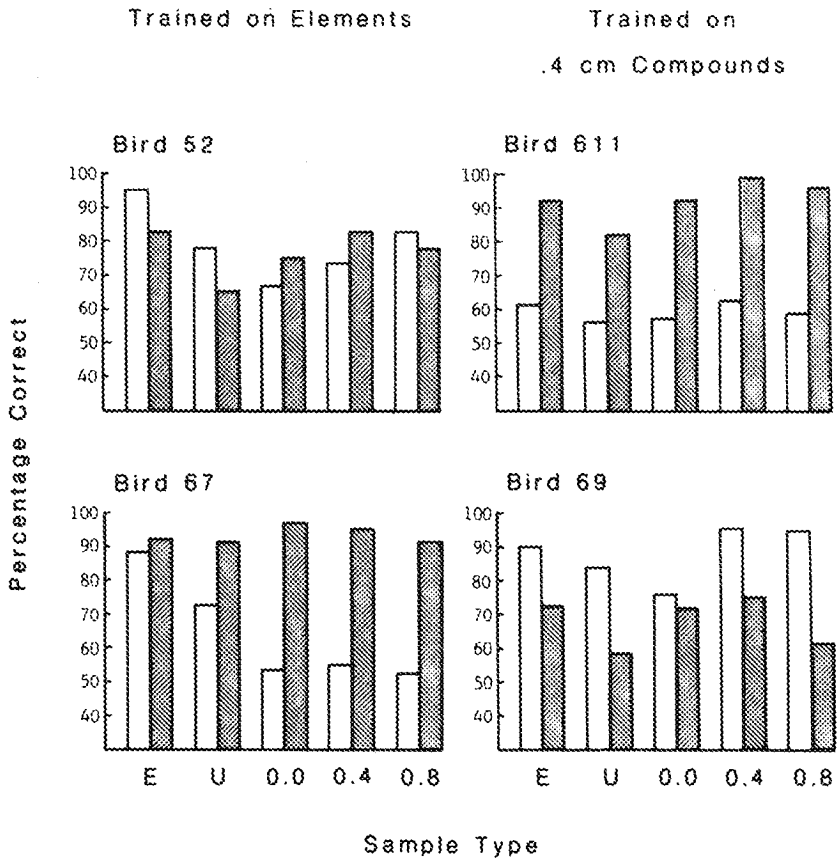

Figure 4. Matching accuracy during the 10-session transfer test of Experiment 2. (The open bar of each pair shows percentage correct on color tests, while the speckled bar shows percentage correct on line orientation tests. (E = element, U = Unified compound, 0.0 = compound with .0-cm spatial separation, etc.)

fer of matching accuracy to element samples. Thus, the asymmetrical transfer effect observed in Experiment 1 was not obtained when a true MTS procedure, rather than symbolic matching, was used. This result is consistent with the recent findings of Grant and MacDonald (1986), who also found transfer between element and compound true matching performance, regardless of whether birds were trained to match elements or compounds.

Thus, some difference between symbolic and true MTS produces the asymmetrical transfer effect in the former but not the latter procedure. Whether true MTS and symbolic MTS involve different psychological processes is a matter of debate (e.g., Carter & Eckerman, 1975; Zentall, Hogan, & Edwards, 1984). It is possible that a difference in processes used to mediate true as opposed to symbolic matching, such as the use of an "identity concept" (Zentall et al., 1984), is responsible for the difference in the results of Experiments 1 and 2. However, the available theories of differences between true and symbolic matching do not provide any obvious explanation for the pattern of results that was obtained. Operationally, the sole difference between the two procedures is that in true matching the correct test stimulus is physically identical to the sample (or a dimensional component of the sample), whereas in symbolic matching the sample and correct test stimulus have no systematic physical relation. This difference provides an explanation for the results within the framework of compound stimulus dissociation: Presentation of elements in isolation from the compounds produces compound stimulus dissociation and allows the processing of compound stimuli in terms of their elements.

The immediate transfer of matching ability from Phase 1 of training to Phase 2 that was found in Experiment 1 was not found in the present experiment. This supports the hypothesis that training Phase 0 of Experiment 1 was responsible for producing the ability to match the second training sample subset immediately upon presentation. If true, this reduces the mystery surrounding the difference in acquisition rates of the birds trained with element and compound samples in Experiment 1. On the other hand, it requires that under at least some conditions pigeons acquire matching ability that they do not exhibit. The possibility of such a learning/performance distinction in the matching-to-sample paradigm deserves further investigation.

General Discussion

The primary findings of the present experiments can be summarized as follows. Pigeons trained in a symbolic MTS task with element samples demonstrated transfer of matching accu-

racy to compound samples. Pigeons trained with compound samples in the same symbolic matching task, however, were unable to match element samples. Training in a true MTS task with either compound or element samples allowed successful matching of both.

The most important implication of these data is that pigeons can represent color/line orientation compound stimuli in either an analytic or a unitary manner. The evidence for this hypothesis is the asymmetrical transfer of matching accuracy found in Experiment 1. This finding is consistent with the hypothesis that element-trained birds matched the compound samples on the basis of their element values, whereas compound-trained birds did not. It has been argued that element-to-compound transfer can be explained by stimulus generalization processes even if compounds are not processed analytically (Grant & MacDonald, 1986, p. 163). This view anticipates, however, that transfer should be symmetrical. The fact that transfer was obtained in one direction but not the other implies a difference in the psychological processes used following element as opposed to compound training (see also Grant & MacDonald, 1986, p. 165).

Transfer did occur from the 0.4-cm compounds to the other compounds presented in the transfer test, including the Unified compound. Thus, transfer based on stimulus generalization did occur. Why, in Experiment 1, matching rules generalized to the seemingly dissimilar Unified compounds, but not to the element samples (even given that the compounds were not processed in an analytic fashion), will require further experimental analysis. Perhaps element samples, being equally similar to two of the training compounds, were not able to evoke the matching rules associated with either. Clearly, however, the lack of compound-to-element transfer in Experiment 1 implies that the compounds had not been matched in terms of elements during training. The fact that transfer occurred from element training to the Unified compounds implies that these stimuli were processed in an analytic fashion in the present experiments.

The results support the view that at least under some conditions compound stimuli are initially represented in a unitary fashion and come to be processed in terms of their elements through the action of a learning process. This learning process is to be contrasted with associative learning processes. Associative learning is generally conceived of as resulting in "links," "bonds," or "associations" between representations of two or more stimuli. In contrast, "dissociative" learning may be conceived of as resulting in a change in the representations themselves rather than in the associations between them. In particular, a single representation is dissociated or decomposed into two or more representations.

Exposure to the element stimuli produced dissociation of the compound stimuli used in the present experiments. This is shown by the results of Experiment 2, in which birds trained in a compound matching task in which the elements served as test stimuli showed transfer of matching accuracy from the compound task to the element task. Because these birds were exposed to the same formal procedure as the birds in the compound training condition of Experiment 1, the successful transfer found in Experiment 2 can be attributed to the use of the elements as test stimuli. Thus, stimulus dissociation is produced as a result of presentation of the elements either as sample stimuli (the element training group of Experiment 1) or as test stimuli (the compound training group of Experiment 2).

Learning processes responsible for the division of stimulus compounds into elements have been previously proposed by James (1890/1950) and Gibson (1969). Gibson proposed that presentation of stimulus elements in a variety of combinations produces dissociation. That is, differentiation of a stimulus feature such as a particular shape is the result of presenting the shape in combination with a variety of other attributes (e.g., red square, green square, yellow square). Support for this hypothesis comes from the experiments of Turnure and Wallace (1965), who presented human subjects with a target feature embedded in larger line drawings. Subjects who had been presented with the target embedded in a variety of compounds recognized the target better than did subjects who had seen only a single compound. It is important to note that subjects in the present experiments were exposed to analogous conditions; for example, red was presented in combination with both vertical and horizontal. Thus, one condition prescribed by Gibson for producing stimulus differentiation apparently did not produce it under the present conditions. It is possible, however, that there was an insufficient number of element combinations in the present experiments. Perhaps if a larger number of line orientation and color values had been used, dissociation would have occurred without element presentation.

Many theories of learning have assumed that associative strength is assigned primarily to the elements of compound stimuli rather than to the compound as a whole (e.g., Mackintosh, 1975; Pearce & Hall, 1980; Rescorla & Wagner, 1972). The present results indicate, however, that at least some compounds are processed in a unitary fashion and without reference to their elements until the conditions that produce analytic processing are provided. Thus, the functional stimulus in a given situation may be affected by the previous experience of the subject with the nominal stimulus elements.

Although the present experiments focused on the issue of unitary versus analytic compound stimulus representations, the data have additional implications for theories of the element/compound difference in compound MTS. One of the original goals of the present research was to determine whether or not the element/compound difference would be obtained under conditions of symbolic MTS. Such a finding would rule out the generalization decrement account of the element/compound difference, which relies on the fact that in true MTS the element test stimuli are more similar to the element sample stimuli than to the compound sample stimuli (Cox & D'Amato, 1982; Maki et al., 1976; Roberts & Grant, 1978). Under the conditions of symbolic MTS used in Experiment 1, significant element/compound differences were obtained in two out of the three element-trained birds during the transfer test. These data must be interpreted with caution, however, because previous reports have focused on data collected after substantial experience matching compound samples rather than immediately upon compound sample introduction. Although not reported in the present article, only 1 of the 3 birds showed evidence of an element/compound difference after 40 sessions of matching the entire sample set (Brown, 1985). Thus, the presence of element/compound differences seems to have been reduced relative to the consistent effects found in previous experiments using the

true MTS procedure (e.g., Lamb & Riley, 1981; Maki & Leith, 1973; Roberts & Grant, 1978; Santi, Grossi, & Gibson, 1982). Although this might be taken as evidence for the generalization decrement hypothesis, the mixed pattern of results does not allow any strong statement about whether the element/compound difference is obtained in symbolic MTS.

Grant and MacDonald (1986) found that birds trained with element samples in a true MTS procedure subsequently matched element samples more accurately than compound samples, whereas birds trained with compound samples showed superior compound matching ability. This finding, they argued, provides support for a coding decrement explanation of the element/compound difference. This hypothesis assumes that compound samples are processed in a unitary manner. Accurate matching of compound samples after element training (which is the training procedure used in all previous compound MTS experiments) requires that the appropriate element matching rule be invoked by presentation of the compound. Inferior compound matching is produced because compound matching depends on stimulus generalization from the previously trained element samples to the novel compound samples. The present findings question this hypothesis because its assumption that compounds are processed in a unitary fashion is made unlikely by the fact that Grant and MacDonald's compound-trained birds received element exposure before and during training. However, Grant and MacDonald's results do show that the common practice of training birds to match element stimuli prior to compound introduction may contribute to the element/compound difference. The results of Experiment 2, which consist of essentially the same experimental design as used by Grant and MacDonald, provide some degree of support for this proposal. Element-trained birds in that experiment showed the typical element/compound difference. Although compound-trained birds did not show the compound superiority found by Grant and MacDonald, they failed to demonstrate element superiority.

The present results support the assumption of the shared-attention hypothesis that compound samples used in MTS experiments are processed analytically since all previous MTS experiments have included presentation of element stimuli in the form of samples and/or test stimuli. However, the present results also provide some evidence that factors other than information overload contribute to the element/compound difference. Although there is good evidence that attentional effects do occur under some conditions in the context of MTS (e.g., Brown, Cook, Lamb, & Riley, 1984; Lamb, 1982), it may be that a number of factors combine to produce the element/compound difference (cf. Cook, Riley, & Brown, 1986).

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Received March 31, 1986
Revision received July 18, 1986 ■