The nature of the response in Simon discriminations by pigeons

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Spence (1952) postulated that under some conditions, responding in simple discriminations is controlled by compounds or patterns consisting of the nominal discriminative cue, plus its spatial position. Stimulus control by such compounds was said to develop when no single cue or element was systematically reinforced more than any other. This analysis has been applied to good effect in understanding some peculiar accuracy results obtained from pigeons performing Simon discrimination tasks. This article describes how Spence's cue–position analysis provides a better account of pigeons' performance in this task than do nominal cue-only and configurational views of the functional discriminative stimuli. Adding a value transfer assumption improves the ability of the cue–position hypothesis to account for the accuracy data.

The title of my article is a deliberate variation on the title of Spence's 1952 *Psychological Review* article ("The Nature of the Response in Discrimination Learning"). The reason for this is that the discrimination learning analysis that Spence described in that article is apropos to understanding the rather peculiar accuracy profiles exhibited by pigeons performing a Simon task (Urcuioli, 2006; Urcuioli, Vu, & Proctor, 2005). The Simon task and the unusual accuracy results will be described momentarily. First, however, it is worthwhile and instructive to review Spence's main points and reasoning in his 1952 article. That will set the stage for showing how the discrimination analyses he discussed can be applied to the Simon task and why one particular analysis is best suited for explaining how pigeons perform this task.

From the perspective that subjects approach the positive (reinforced) stimulus in discrimination learning, Spence (1952) addressed an issue that he had not previously—namely, how to account for accurate successive discrimination performance. For instance, consider a task in which rats must learn to turn left in a T-maze when both arms are white, and right when both arms are black. Obviously, any analysis stating that rats merely learn to approach the nominal black or white cues will be unsuccessful in accounting for their performances, because approaching black or white per se will be reinforced only 50% of the time. In other words, without differential reinforcement associated with black versus white, no discrimination learning is possible. Contrast this with a simultaneous black–white discrimination task in which, say, approaching white is reinforced, but approaching black is not. Here, there is a clear reinforcement differential vis-à-vis these cues that can obviously support discrimination learning.

To explain successive discriminations, Spence (1952) argued that compounds, or "patterns," consisting of white-on-the-left and black-on-the-right would acquire excitatory properties during discrimination training, because approaching these cue–position compounds would be differentially reinforced (viz., in comparison with nonreinforcement for approaching white-on-the-right and black-on-the-left). Spence described the conditions that should promote such cue–position learning and contrasted them with conditions more likely to promote cue-only or configurational control. In essence, he said that cue–position learning would develop only when no single cue member was systematically reinforced more than any other. Conversely, configurational learning (learning to respond on the basis of the total stimulus configuration present on a trial) should occur "in nonarticulate organisms" (Spence, 1952, p. 92) only when the training contingencies do not permit simpler solutions—namely, learning on the basis of a single element or a cue–position pattern.

Spence (1952, p. 90) remarked that this insight was really "nothing new," citing similar ideas expressed by Pavlov (1927) and Hull (1943). Nevertheless, the general idea that the controlling or functional discriminative stimuli might be more complex than (or different from) what appears at first glance (see, e.g., McIlvane, Serna, Dube, & Stromer, 2000) was worth underscoring, if not repeating. Indeed, despite many instances of this in research from my laboratory (e.g., DeMarse & Urcuioli, 2005; Lionello & Urcuioli, 1998; Urcuioli, 2007), I would have arrived at an understanding of pigeons' accuracy in a Simon discrimination sooner had I reread Spence.

In this article, I will offer a Spence-like view that the functional stimuli for pigeons performing a Simon task are "What did I see?" and "Where did I see it?"—in other

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words, cue–position compounds or patterns. I will contrast this perspective with cue-only and configurational perspectives to show how well (or how poorly) these alternatives can account for the data. I will argue that Spence's analysis works the best and that although it cannot fully capture all of the findings, it remains integral to a more comprehensive explanation that does.

The Simon Discrimination Task

The Simon task is a two-alternative discrimination in which subjects must make one spatial response (e.g., "left") to one cue and the alternative spatial response (e.g., "right") to another cue. Across trials, each cue appears randomly either at the spatial location corresponding to the required response or at the opposite, or noncorresponding, location. Although the cue's spatial location is irrelevant to correct performance, this variable nonetheless strongly affects the speed with which humans (see, e.g., Simon, 1990; Simon & Rudell, 1967) and pigeons (Urcuioli et al., 2005) make the required spatial responses. In particular, subjects are faster to respond correctly when the cue appears at the same location as the required response (i.e., on corresponding trials) than when the cue appears at the location opposite of the required response (i.e., on noncorresponding trials). This reliable finding is known as the *Simon effect* (see Hedge & Marsh, 1975; Lu & Proctor, 1995; Simon, 1990).

Figure 1 shows a partial schematic of a Simon discrimination task developed for use with pigeons (Urcuioli et al., 2005). On each trial, pigeons must make either a left- or a right-key spatial response. A left keypeck is reinforced when red (R) appears on either key (top row), and, conversely, a right keypeck is reinforced when green (G) appears on either key (bottom row). On half of the trials, the spatial-response cue (R or G) appears on the same key that pigeons must peck for reinforcement (left column). In other words, on these corresponding trials, pigeons peck directly at either R or G for reinforcement; pecking the key displaying the alternative (e.g., white [W]) stimulus is nonreinforced. On the other half of the trials, the spatial-

response cue appears on the key that is opposite the one pigeons must peck for reinforcement (right column). On these noncorresponding trials, pigeons must peck "away from" the spatial location showing R or G to obtain reinforcement (i.e., reinforcement is contingent on pecking the key displaying the alternative stimulus). The spatial-response cue for each trial is actually obtained by pecking once to a center-key "trial-ready" stimulus that's accompanied by the alternative stimulus on both side keys. This trial-ready display and contingency (not shown in Figure 1) were included because the task was designed to obtain reliable measures of left–right response latencies (i.e., to evaluate possible Simon effects).

After pigeons have learned the Simon discrimination contingencies, they typically peck the correct left or right key faster on corresponding than on noncorresponding trials (see Urcuioli et al., 2005); that is, they exhibit a Simon effect. However, with continued discrimination training, the *accuracy* with which they make these spatial responses is lower on corresponding than on noncorresponding trials. In other words, when they must peck directly at either R or G for reinforcement, they do so less often than when they must peck away from R or G (i.e., to the alternative stimulus). Figure 2 shows examples of this accuracy difference for two groups trained on variations of the Simon task depicted in Figure 1 (see also Urcuioli, 2006). For these groups, the spatial-response cues were red (R) and yellow (Y), and there were two possible alternative stimuli—white (W) and blue (B)—that could appear with them (in order to equate exposure to all task stimuli). For Group 1, the W and B alternatives simply varied across trials. For Group 2, they also changed within trials in the transition from the trial-ready display to the discriminative display. Both groups nonetheless exhibited lower accuracy on corresponding than on noncorresponding trials (compare filled- vs. open-symbol functions). This is precisely the opposite of what humans exhibit if they show an accuracy difference in the Simon task. The pigeon results are also surprising given their tendency to approach and contact signals for reinforcement (Hearst & Jenkins, 1974) and because the difference occurs after they have already achieved high levels of accuracy on the corresponding trials. In other words, corresponding-trial accuracy literally drops as training continues beyond the point at which pigeons are responding accurately on both corresponding and noncorresponding trials (e.g., after Session 3 or Session 4 in Figure 2).

Even more peculiar is the finding that this effect is substantially larger when correct responses on the corresponding trials are reinforced only 50% of the time (see Figure 3). In this partial reinforcement version of the Simon task (cf. Urcuioli, 2006, Experiment 5), food reinforcement is delivered with a probability of .5 for correctly pecking R or G as opposed to the 1.0 probability in the standard task (see Figure 1). Pecking R and G on the corresponding trials that do not end in reinforcement simply turns off the display. This procedure equates the overall probability of reinforcement for pecking R, G, and the alternative stimulus (or stimuli) across both trial types (i.e., to .5). Pigeons still exhibit the latency differ-

Figure 1. The four left key–right key combinations of stimuli in a Simon discrimination task with pigeons (cf. Urcuioli et al., 2005). R, red; W, white; G, green; +, reinforced stimulus; –, nonreinforced stimulus. Corresponding trials are those in which the stimulus signaling a reinforced left keypeck or a reinforced right keypeck appears on that key. Noncorresponding trials are those in which the stimulus signaling a reinforced left keypeck or a reinforced right keypeck appears on the opposite key.

Figure 2. The percentage of correct choices on the corresponding and noncorresponding trials of a standard Simon discrimination task (see Figure 1) over successive training sessions by two similarly trained groups of pigeons.

ences defining the Simon effect under these conditions, indicating that the effect is not attributable to reinforcement factors per se. But more interesting is the finding that pigeons trained with partial reinforcement for correct corresponding-trial choices come to choose the *incorrect* stimulus more often than the correct stimulus on these trials. As Figure 3 shows, corresponding-trial accuracies fall to levels well below chance! This bizarre result is not simply an effect of partial reinforcement, given that accuracies on the noncorresponding trials remain very high.

Obviously, the reliable but peculiar accuracy difference between corresponding- versus noncorresponding-trial performance in the pigeons' Simon task demands some explanation. In the following section, I consider three possible accounts discussed by Spence (1952).

The Nature of the Simon Discrimination Response

Configurational responding. The top half of Table 1 presents a configurational perspective (Gulliksen & Wolfe, 1938; see also Pearce, 1994) of pigeons' choice responding in the standard Simon task. The left column lists each left-right configuration of the R or G stimulus with the alternative W stimulus. The adjacent and rightmost columns list the correct (reinforced) left or right response for each configuration and the trial type (corresponding or noncorresponding), respectively. Continuous reinforcement [$p(\text{Reinforcement}) = 1.0$] for each correct response is also shown. According to a configurational account, pigeons make a left or a right keypeck on the basis of the total stimulus pattern, or the *cue-cue relation* (Spence, 1952), appearing on each trial. For example, if the pigeon sees the pattern of R on the left key and W on the right key, or the reverse pattern, it pecks left. Conversely, if it sees G on the left key and W on the right key, or the reverse pattern, it pecks right.

It should be obvious that in the absence of any supplemental assumptions, configurational learning of this sort predicts neither the Simon effect itself (viz., shorter response latencies on corresponding than on noncorresponding trials) nor lower accuracy on corresponding trials with prolonged training. Why, for instance, should pigeons be faster to make a left keypeck when the left-right stimulus display is R-W than when the display is W-R if they look at both keys prior to making their choice? Likewise, why should they perform more poorly after seeing certain combinations of left- and right-key stimuli (viz., R-W and W-G) than after seeing other combinations (viz., W-R and G-W)?

The bottom half of Table 1 extends this perspective to the condition in which correct corresponding-trial responses are only partially reinforced (see Figure 2). Here, given that the R-W and W-G cue-cue patterns yield

Table 1
A Configurational Perspective of Pigeons' Choice Responding in a Standard Simon Discrimination Task and With Partial Reinforcement for Correct Corresponding-Trial Choices

Configuration	Response	$p(\text{Reinforcement})$	Trial Type
Standard Task			
R-W	left	1.0	corresponding
W-R	left	1.0	noncorresponding
G-W	right	1.0	noncorresponding
W-G	right	1.0	corresponding
Task With Partial Reinforcement			
R-W	left	.5	corresponding
W-R	left	1.0	noncorresponding
G-W	right	1.0	noncorresponding
W-G	right	.5	corresponding

Note—R, red; W, white; G, green. Configurations show stimuli on left and right keys, respectively.

Figure 3. The percentage of correct choices on the corresponding and noncorresponding trials of a Simon discrimination with partial reinforcement ($p = .5$) for correct corresponding-trial choices over successive training sessions.

reinforcement only 50% of the time, one might predict slower discrimination acquisition on these (corresponding) trials than on the noncorresponding trials. However, it is not clear how a configurational view would explain the especially low terminal levels of accuracy on the corresponding trials under these conditions, and it is certainly challenged by the finding that such accuracies eventually fall to below-chance levels (see Figure 3).

Cue-only and cue-position responding. Table 2 summarizes the reinforcement probabilities for pecking the various stimuli in a standard Simon discrimination task (see Figure 1) from the perspective that the functional stimuli are either the nominal cues themselves (cue-only) or cue-position compounds (Spence, 1952).

From a cue-only perspective, these probabilities are .5 for all stimuli, because if pigeons simply peck R or G or W independently of where these colors appear in a trial (i.e., on the left or on the right key), then they will be reinforced only half of time. For example, pecking R is always reinforced when it is on the left key, but pecking R is never reinforced when it is on the right key. Given the absence of a reinforcement differential (i.e., no color is reinforced any more frequently than any other), responding simply

on the basis of color alone cannot produce acquisition of the Simon discrimination, and pigeons clearly do acquire this task (see Figure 2). Another “solution” must underlie acquisition.

From a cue-position perspective, pigeons learn to respond to what color they see (R, G, or W) and where they see it (on the left or right key), yielding a total of six compound stimuli. Note that the reinforcement probabilities differ substantially across the color-position compounds in a manner that can support acquisition. For instance, given that R signals that a left keypeck will be reinforced (see Figure 1), pecking R when it appears on the left key (R left) is always reinforced ($p = 1.0$). Conversely, pecking R when it appears on the right key (R right) is never reinforced ($p = 0$). Similarly, given that G signals that a right keypeck will be reinforced, pecking G when it appears on the right key (G right) is always reinforced, but pecking G when it appears on the left key (G left) is never reinforced. The W-left and W-right stimuli are reinforced 50% of the time, because pecking W on the left key and pecking W on the right key are never reinforced (0) on corresponding trials, but are always reinforced (1.0) on noncorresponding trials. With equal numbers of corresponding and noncorresponding trials, this yields an overall probability of reinforcement of .5.

On both corresponding and noncorresponding trials, there is a reinforcement differential between the two cue-position compounds appearing on each trial, so this should support discrimination acquisition. For example, pigeons choose between R left (correct) and W right or between G right (correct) and W left on the corresponding trials. The reinforcement probabilities associated with the former two stimuli are 1.0 and .5, respectively, as they are for the latter two stimuli. On noncorresponding trials, pigeons choose between R right and W left (correct) or between G left and W right (correct). Here, the reinforcement probabilities are 0 and .5, respectively, for the stimuli comprising each of those two pairs.

Table 2
Probability of Reinforcement for Pecking the Functional Stimuli Hypothesized by Cue-Only and Cue-Position Perspectives of a Standard Simon Discrimination Task

Cue-Only		Cue-Position	
Stimulus	$p(\text{Reinforcement})$	Stimulus	$p(\text{Reinforcement})$
R	.5	R left	1.0
G	.5	R right	.0
W	.5	G left	.0
		G right	1.0
		W left	.5
		W right	.5

Note—R, red; G, green; W, white.

Because the reinforcement differential is identical for both corresponding and noncorresponding trials (viz., .50), this would seem to predict that acquisition and steady-state performances should also be identical. Clearly, they are not: Pigeons are initially more accurate but eventually become less accurate on the corresponding trials (see Figure 2). Note, however, that a position stating that choices are a function of the size of the reinforcement probability difference implies that pigeons compare the two stimuli appearing on a trial prior to making a choice—a notion akin to configurational learning. In fact, pigeons in left- versus right-key choice situations tend to view each stimulus serially and, for each observation, make a “peck” versus “do not peck” decision (Wright, 1992; Wright & Sands, 1981).

Combining this “look-and-decide” observational pattern with the reinforcement probabilities associated with each cue–position stimulus actually predicts lower corresponding-trial than noncorresponding-trial accuracies. Consider, for instance, that two excitatory stimuli appear on each corresponding trial—an always reinforced stimulus (e.g., R left) and a partially reinforced stimulus (e.g., W right). The presence of the latter stimulus should periodically yield (incorrect) pecks to it—especially when observed first—thus lowering overall accuracy on these trials. By contrast, only one excitatory stimulus appears on noncorresponding trials—the partially reinforced W-left or W-right stimulus. Its companion stimulus (R right or G left) is never reinforced and, so, should rarely be pecked (i.e., it should not interfere with pecking W left or W right). In the absence of any interference from the S– stimulus on the noncorresponding trials, these accuracies should asymptote at very high levels—well above those on the corresponding trials. This is precisely what is observed.

That leaves the finding that, initially, corresponding-trial accuracies are higher (not lower) than noncorresponding-trial accuracies to be explained. Indeed, this initial difference is often quite substantial, as can be seen in Figures 2 and 3. But the effect is neither as interesting nor as important as it may appear, because it occurs before the Simon discrimination is learned (i.e., when overall accuracy is near 50% correct). The presolution difference likely reflects pigeons’ preferences for the task-relevant, spatial-response color cues (see also Hearst & Jenkins, 1974). More interesting is the fact that the initial preference does not simply dissipate as the Simon task is learned; it reverses.

The notion that excitatory cue–position S– stimuli present on corresponding trials interfere with accurate performances on these trials and, conversely, that the absence of such stimuli on the noncorresponding trials facilitates accurate performances on those trials is similar to the explanation given for performance differences typically seen in ambiguous-cue discriminations (Fletcher, Grogg, & Garske, 1968; Thompson, 1954). Ambiguous-cue tasks consist of two simultaneous discriminations in which the S– for one discrimination serves as the S+ for the other (the so-called ambiguous, or A, cue). The typical finding is that accuracy on trials in which the A cue is the S– alongside an always reinforced, positive (P)

cue (PA trials) is lower than accuracy on trials in which the A cue is an S+ alongside a never reinforced, negative (N) cue (NA trials). The explanation for this difference—the interfering cue hypothesis (Fletcher & Garske, 1972; Zeaman & House, 1962)—states that lower accuracy on PA trials arises because subjects are choosing between two excitatory stimuli, the always reinforced P stimulus and the partially reinforced A stimulus, and that the excitatory properties of the latter interfere with selection of the former. No such interference occurs on NA trials, because the N stimulus has no excitatory value. The analogy to the Simon discrimination should be obvious. Indeed, I have argued elsewhere (Urcuioli, 2006; see also Urcuioli & Michalek, 2007) that the pigeon’s Simon task is actually two concurrent ambiguous-cue discriminations.

Extensions to Simon Tasks With Partial Reinforcement

Table 3 summarizes the probability of reinforcement for pecking each functional stimulus from the cue-only and cue–position perspectives when correct corresponding-trial responses are reinforced only 50% of the time. To make these calculations, I assumed 80 discrimination trials per session divided equally between corresponding and noncorresponding trials.

Unlike the standard task, there is now a reinforcement differential associated with just the nominal cues (R, G, and W). The probability of reinforcement for pecking R and pecking G (independently of where they appear) is only .25, whereas the probability of reinforcement for pecking W is .50. The former value reflects the fact that R and G are each reinforced on only 10 of the 20 corresponding trials on which they appear and are never reinforced on the 20 noncorresponding trials on which they appear. The latter value (.50) for pecking W is identical to that in the standard task, because continuous reinforcement continues to operate on the noncorresponding trials. Given these differences, pigeons should show a preference for pecking W, which, in turn, should yield better-than-chance accuracy on noncorresponding trials (where pecking W is “correct”) and lower-than-chance accuracy on corresponding trials (where pecking W is “incorrect”). These predictions qualitatively match the observed results (see Figure 3).

Table 3
Probability of Reinforcement for Pecking the Functional Stimuli Hypothesized by Cue-Only and Cue-Position Perspectives of a Simon Discrimination Task With Correct Corresponding-Trial Choices Reinforced 50% of the Time

Cue-Only		Cue-Position	
Stimulus	<i>p</i> (Reinforcement)	Stimulus	<i>p</i> (Reinforcement)
R	.25	R left	.5
G	.25	R right	.0
W	.50	G left	.0
		G right	.5
		W left	.5
		W right	.5

Note—R, red; G, green; W, white.

However, given how pigeons observe stimuli in two-choice tasks (Wright, 1992; Wright & Sands, 1981), the cue-only account has difficulties explaining the very high levels of accuracies on the noncorresponding trials. After all, two excitatory stimuli appear on these trials—W and R (or G)—so the presence of the excitatory R or G stimulus should interfere to some degree with the choice of W. This is certainly not obvious, given the roughly 100% noncorresponding-trial accuracies after seven or eight training sessions (see Figure 3).

From a cue-position perspective, partially reinforcing correct corresponding-trial choices eliminates the reinforcement probability differential between the two stimuli appearing on those trials. For example, pecking R on the left key pays off 50% of the time, as does pecking its companion stimulus, W, on the right key. Similarly, pecking G on the right key pays off 50% of the time, as does pecking W on the left key. This should produce indifference between the respective stimuli (*viz.*, 50% accuracy). Instead, corresponding-trial accuracies under these conditions eventually fall to levels below chance (see Figure 3)—a point to which I will later return.

However, a cue-position account does correctly predict that accuracies on the noncorresponding trials should be unaffected by partial reinforcement of corresponding-trial choices. The reason is that the probability differential between stimuli appearing on the noncorresponding trials remains at .50 in comparison with the standard task, and that one of the two stimuli on these trials should have no excitatory properties since it is never reinforced (*viz.*, R right and G left). Consequently, these compounds should not interfere with correct choice of W left or W right, respectively.

Considering only this version of the Simon task, the cue-only and cue-position perspectives account for the results equally well (or equally poorly). The former predicts below-chance accuracies on partially reinforced corresponding trials, whereas the latter does not. On the other hand, the latter predicts the very high levels of accuracies observed on the noncorresponding trials, whereas the former does not. However, with a supplemental assumption that will be described later, the cue-position account can also predict below-chance accuracies on partially reinforced corresponding trials. Moreover, even without that assumption, it provides a better account of performances when the *noncorresponding* trials are partially reinforced.

Figure 4 shows these data—labeled as “ $p = .5(n)$ ”—along with data from the standard Simon discrimination, and the task with partial reinforcement for corresponding-trial performances, labeled as “ $p = .5(c)$.” The black and gray bars show accuracies on corresponding and noncorresponding trials, respectively.

A correction procedure was in effect throughout the manipulations shown in Figure 4: Any incorrect choice caused the trial on which it occurred to be repeated. This tends to elevate overall levels of accuracy. In this situation, the elevation is evident by higher accuracy on the corresponding trials than that which occurs without a correction procedure (see Figure 2). Nevertheless, corresponding-

Figure 4. The percentage of correct choices on the corresponding (black bars) and noncorresponding (gray bars) trials over the last five sessions of a Simon discrimination task with reinforcement for all correct choices [standard], partial reinforcement for correct noncorresponding-trial choices [$p = .5(n)$], or partial reinforcement for correct corresponding-trial choices [$p = .5(c)$].

trial accuracy is still lower than noncorresponding-trial accuracy.

Reducing the probability of reinforcement to .50 on the noncorresponding trials had absolutely no effect on those accuracies, but it *increased* accuracies on the corresponding trials as compared with the standard task. By contrast, reducing the probability of reinforcement to .50 on the corresponding trials caused those accuracies to drop as compared with the standard task, but had no effect on noncorresponding-trial accuracies (although this might have been obscured by a performance ceiling).

Table 4 shows the probability of reinforcement for each functional stimulus vis-à-vis the cue-only and cue-position perspectives when correct noncorresponding-trial choices are reinforced only 50% of the time. Once again, there are different reinforcement probabilities associated with the functional stimuli from a cue-only perspective. Pecking R and pecking G—independently of where they appear—are reinforced 50% of the time, whereas pecking W independently of where it appears is reinforced only 25% of the time. This should result in a preference for R (and for G)

Table 4
Probability of Reinforcement for Pecking the Functional Stimuli Hypothesized by Cue-Only and Cue-Position Perspectives of a Simon Discrimination Task with Correct Noncorresponding-Trial Choices Reinforced 50% of the Time

Cue-Only		Cue-Position	
Stimulus	$p(\text{Reinforcement})$	Stimulus	$p(\text{Reinforcement})$
R	.50	R left	1.0
G	.50	R right	.0
W	.25	G left	.0
		G right	1.0
		W left	.25
		W right	.25

Note—R, red; G, green; W, white.

over W, which, in turn, should yield above-chance accuracy on corresponding trials (where pecking R or G is correct) and below-chance accuracy on noncorresponding trials (where pecking R or G is incorrect). The results shown in Figure 4 are consistent with the former prediction, but they clearly contradict the latter prediction.

From a cue-position perspective, partially reinforcing choices on the noncorresponding trials increases the reinforcement probability difference between the compound stimuli appearing on the corresponding trials by lowering the values associated with the W-left and W-right stimuli. For instance, the probability of reinforcement for pecking R left is 1.0 versus only .25 for pecking W right as compared with 1.0 versus .50, respectively, in the standard task (see Table 2). Because W right should have a lower excitatory value under this partial reinforcement condition, it should produce less interference with the (correct) selection of R left. Less interference, in turn, should increase corresponding-trial accuracy, as compared with the standard task. This prediction is clearly supported by the data shown in Figure 4. Also, unlike the cue-only account, the cue-position account does not predict any change in accuracy on noncorresponding trials—despite partial reinforcement on those trials—because pigeons continue to choose between a (relatively weak) excitatory stimulus (e.g., W left) and a stimulus with zero excitatory value (e.g., R right).

When all versions of the pigeon Simon discrimination task are considered together, the cue-position account provides a better overall match to the observed data than a cue-only account. It also provides a better account than a configuration analysis because, as mentioned earlier, the latter fares poorly in accounting for lower accuracies on corresponding than on noncorresponding trials in the standard task and for below-chance accuracy on corresponding trials that are partially reinforced.

Of course, the latter criticism applies to the cue-position account as well. Without other assumptions, it predicts only chance levels of corresponding-trial accuracy—not the below-chance levels of accuracy actually observed. However, by appealing to the process of value transfer, a cue-position account can predict those results as well.

A Value Transfer Assumption

There is now good evidence that in simultaneous discriminations—like those comprising the Simon task—some of the excitatory value that accrues via reinforcement to the S+ stimuli transfers to the S− stimuli that accompany them (e.g., Urcuioli & Michalek, 2007, Experiment 2; Zentall & Sherburne, 1994). According to value transfer theory (von Fersen, Wynne, Delius, & Staddon, 1991), the total excitatory value of any stimulus in a simultaneous discrimination is the sum of its direct value (viz., the value obtained by direct reinforcement of that stimulus) plus its indirect value (viz., the value transferred to it by an S+ with which it appears). A particular stimulus's direct value is proportional to the reinforcement probability associated with it, so a partially reinforced S+ will have less direct value than it would if that same S+ is always reinforced.

Table 5 uses this value transfer idea to calculate the total excitatory values of the S+ and S− stimuli appearing on the corresponding trials of a standard Simon task (top) and one in which correct corresponding-trial choices are reinforced only 50% of the time (bottom). I arbitrarily chose 10 as the direct value of a stimulus that is always reinforced. A stimulus reinforced only half of the time was assigned a direct value of 5, and a never-reinforced stimulus was assigned a direct value of 0. I assumed that 20% of the direct value of an S+ transfers to the S− stimulus that accompanies it.

To understand all of the numbers shown in Table 5, it is important to recognize that even though W right and W left are the S− stimuli on the corresponding trials, they nonetheless have greater-than-zero direct values because these same stimuli appear as the S+ stimuli on the noncorresponding trials (not shown in Table 5). Hence, over all trials (corresponding and noncorresponding), W right and W left are reinforced half of the time, giving them a direct value of 5. Note also that value transfers only from the S+ to the S− on a trial (Clement, Weaver, Sherburne, & Zentall, 1998). Consequently, value transfers from R left to W right, but not vice versa.

With 20% of the direct value of the S+ stimuli transferring to the S− stimuli, the latter stimuli accrue indirect values of 2 in the standard task. This makes their total excitatory values equal to 7 (5 direct + 2 indirect). Compared with the total excitatory values for each of the two S+ stimuli (10), the sizeable values for W right and W left should produce substantial interference with the correct selection of R left and G right and, in turn, relatively low accuracies on these corresponding trials. Although I have omitted the value computations for the noncorresponding trials (sample calculations can be found in Urcuioli, 2006), suffice it to say that the total values of the S− stimuli on these trials are very low. Thus, they should create very little interference with correct selection of the W stimuli. This is consistent with the observation that noncorresponding-trial accuracies are very high.

More important for the present purposes are the computations shown in the bottom half of Table 5. When correct responses on the corresponding trials are only par-

Table 5
Illustrations of Total Excitatory Values of the S+ and S− Stimuli on the Corresponding Trials of a Standard Simon Discrimination Task and a Task With 50% Partial Reinforcement for Correct Corresponding-Trial Responses

Corresponding-Trial Stimuli		Direct Values		Indirect Values		Total Values	
S+	S−	S+	S−	S+	S−	S+	S−
Standard Task							
R left	W right	10	5	0	2	10	7
W left	G right	10	5	0	2	10	7
Partial Reinforcement Task							
R left	W right	5	5	0	1	5	6
W left	G right	5	5	0	1	5	6

Note—S+, reinforced stimulus; S−, nonreinforced stimulus; R, red; W, white; G, green.

tially reinforced, the direct values of R left and G right (the S+ stimuli) are only 5, matching the direct values of the W-right and W-left S- stimuli, respectively, appearing with them. With value transfer, the total excitatory values for the latter stimuli now exceed those for the S+ stimuli, because W right and W left get a boost in their total values from the value transferred to them by the S+ stimuli that accompany them. If pigeons respond more often to whichever stimulus has the greater total excitatory value, then they should select W right and W left (the S- stimuli) more often than R left and G right (the S+ stimuli) on the corresponding trials of this Simon task. Stated otherwise, their accuracy on these trials should fall below chance. This is precisely what was observed (see Figure 3).

Summary and Concluding Remarks

Looking again at the components of the pigeons' Simon discrimination task (see Figure 1), it may seem obvious that discrimination learning in this task requires that pigeons attend both to what color they see and to where they see it. This, then, is another example of Spence's suggestion that some discriminations require that the functional stimuli be cue-position compounds. Otherwise, discrimination learning might not occur at all.

Another appealing aspect of this analysis is that it fits very nicely with the fact that position or location is a very potent stimulus dimension for pigeons (Lionello & Urcuioli, 1998; Urcuioli, 2007). Even when location is not required for the solution of a discrimination problem, pigeons nonetheless attend to it. The consequence is that the functional stimuli governing their performances are cue-position compounds. For example, in conditional discriminations, such as matching-to-sample, reinforcement is contingent on pecking particular comparison stimuli following particular sample stimuli. Samples and comparisons are often shown at different locations, with samples appearing on the center key of the commonly used three-key displays and the comparisons appearing on the adjacent (left and right) side keys. From the experimenter's perspective, well-trained pigeons appear to have learned, say, to peck a vertical-line comparison (no matter on which side key it appears) following a red sample stimulus, and to peck a horizontal-line comparison (no matter on which side key it appears) following a green sample stimulus. Indeed, if the functional stimuli were vertical, horizontal, red, and green, then matching acquisition should be straightforward, and terminal accuracy levels should be high (and they are).

But what pigeons actually learn is to peck vertical-on-the-left-key after red-on-the-center-key, vertical-on-the-right-key after red-on-the-center-key, horizontal-on-the-left-key after green-on-the-center-key, and horizontal-on-the-right-key after green-on-the-center-key. This can be demonstrated simply by changing the locations at which the samples and comparisons appear after pigeons have learned the standard center-key sample, side-key comparisons task to very high levels of accuracy. When this is done, matching accuracy drops precipitously (Lionello & Ur-

cuioli, 1998), something that should not occur if the functional stimuli were simply the colors and line orientations, *per se*. Furthermore, generating "location-independent" functional matching stimuli requires special training procedures (Lionello-DeNolf & Urcuioli, 2000).

In this instance, then, Spence (1952) was wrong about cue-position learning occurring only when a simpler solution is unavailable. An apparently simpler solution to the matching problem is available (*viz.*, respond just on the basis of the color and line cues themselves), yet pigeons do not take advantage of it. Might it also be, then, that contrary to my early dismissal of a configurational account of the Simon task, pigeons may have nonetheless responded on the basis of cue-cue relations, despite the ostensibly simpler solution of responding on the basis of cue-position compounds?

For reasons already discussed, this seems unlikely. However, a stronger argument against such an account would be to show that pigeons have difficulty learning—or that they cannot learn—a task whose solution requires detecting cue-cue relations. Spence (1952, p. 92) noted that such a task—which he termed *transverse patterning*—requires at least three stimuli (A, B, and C) presented in the following simultaneous discrimination pairs: A+ B-, B+ C-, and C+ A-, where (+) and (-) refer to the reinforced and nonreinforced stimuli, respectively. Note that each individual cue is reinforced only 50% of the time. Likewise, with each individual stimulus appearing equally often in a left versus right location (not depicted), each cue-position compound is also reinforced only 50% of the time. In essence, all individual functional stimuli—however they are defined—are ambiguous cues. The only way in which accurate discriminations can form is for subjects to respond to each S+ stimulus according to which particular (S-) stimulus accompanies it.

Wynne (1996, Experiment 1) reported that pigeons can learn a transverse patterning task, albeit not to particularly high levels of accuracy. However, the three component discriminations in his procedure were trained sequentially rather than concurrently as in the Simon tasks described in the present article. For a configurational account of the Simon task to be viable, pigeons should be able to learn a transverse patterning problem with all trial types trained concurrently. From all indications, they cannot (or they can, but only with extraordinarily extensive training).

Figure 5, for instance, shows the average results that I obtained from four pigeons exposed to a concurrent transverse patterning problem with color stimuli like those used in the Simon task. In this task, pigeons saw three different two-choice simultaneous discrimination trials intermixed randomly in each training session: A+ B-, B+ C-, and C+ A-, using red, green, and white as stimuli counterbalanced in their roles as A, B, and C, and with the left-right positions of each stimulus in a pair counterbalanced over trials. After 60 sessions (including 20 with a correction procedure in which any incorrect choice caused that trial to be repeated), there were absolutely no signs of acquisition. Perhaps there would have been if training had continued beyond 60 sessions. But even if that were the case, postulat-

Figure 5. The average percentage of correct choices in blocks of two sessions on the three trials of a transverse patterning discrimination. The arrow indicates the start of a correction procedure.

ing configurational learning in the Simon task (where such learning is not required for accurate performance) cannot be reasonably justified when, after far more training, pigeons are unable to learn a set of simultaneous discriminations for which configurational learning is required. These transverse patterning data do make perfect sense, however, from the standpoint of pigeons' observational patterns in two-choice discriminations and from the identical overall reinforcement probabilities associated with each individual stimulus and with each stimulus-position compound (viz., .5).

In summary, the cue-position account of discrimination performances described by Spence (1952) captures pigeons' accuracies in the Simon task very well, especially when supplemented by value transfer—a relatively recent theoretical addition to discrimination learning analyses. It is refreshing to see once again that basic ideas about reinforcement and stimulus control discussed over 50 years ago are apropos to understanding new findings in the discrimination literature.

AUTHOR NOTE

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