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Effects of Stimulus Size and Spatial Organization on Pigeons' Conditional Same-Different Discrimination

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Abstract

In two experiments, we explored the effects of varying the size and the spatial organization of the stimuli in multi-item arrays on pigeons' same-different discrimination behavior. The birds had previously learned to discriminate a simultaneously presented array of 16 identical (Same) visual items from an array of 16 nonidentical (Different) visual items, when the correct choice was conditional on the presence of another cue: the color of the background (Castro, Kennedy, & Wasserman, in press). In Experiment 1, we trained pigeons with 7-item arrays and then tested them with arrays containing the same item, but in a variety of sizes. In Experiment 2, we tested the birds with the items grouped in novel locations: the top, the bottom, the left, or the right portions of the display area, which generated different vertical and horizontal alignments. Accuracy scores revealed virtually perfect stimulus generalization across various item sizes and spatial organizations. Reaction times revealed that the birds perceived different sizes of a single icon as the same stimulus (Experiment 1) and that the birds processed vertical arrangements faster than horizontal arrangements (Experiment 2). These results suggest that the pigeons noticed both physical and spatial changes in the stimuli (as shown by their reaction times), but that these changes did not disrupt the birds' discriminating the sameness or differentness of the multi-item arrays (as shown by their accuracy scores).

Keywords

same-different discrimination; relational learning; concept learning; conditional discrimination; pigeons

Abstract concept learning has traditionally been considered to be a uniquely human ability (Descartes, 1637; Locke, 1690; Morgan, 1896). But, comparative research has recently shown that animals too display behaviors that attest to their ability to extract conceptual information from the environment (e.g., Wasserman & Zentall, 2006).

The extent to which animals can learn the relations of sameness and differentness has become a focal concern of this realm of behavioral research. Acquiring a same-different concept requires learning about the *relations* between or among multiple stimuli; the *absolute* properties of the stimuli must be transcended and knowledge of broad applicability must be extracted. So, when an animal has acquired a same-different concept, it should be able to classify collections of novel items as "same" or "different." That is, the animal should be able to *generalize* its acquired knowledge to new collections of stimuli. Such generalization represents the hallmark test for abstract concept learning.

Stimulus generalization usually concerns single stimulus items. Consider the generality of responding to any particular stimulus. The original training item could be changed in size, for example. Here, the item is the same, but it changes along a single dimension: size. Will the animal still classify this item as the “same” as the original training item? Or will this change in size be sufficient for the animal to classify it as “different?” A rigid tie to the original learning might not be particularly adaptive because objects in the environment must be recognized under many different circumstances: in different lighting conditions, from various distances, and at various angles in the visual field. So, it seems reasonable to imagine that animals might recognize objects as the same despite those and many other possible variations.

Nonetheless, there is a considerable evidence showing that changes in such physical stimulus properties as color, brightness, pitch, or loudness, generate lawful (generalization) decrements in animals’ acquired behavior (Honig & Urcuioli, 1981). For example, Guttman and Kalish (1956) trained pigeons to peck a lighted key and they later tested the birds with different spectral values, both shorter and longer than the training value, spaced 10 nm apart. When the pigeons’ responses were plotted as a function of wavelength, clear decremental stimulus generalization gradients were observed around the training value. So, the testing colors did not prove to be the same as the training color for the pigeons (for a detailed review on stimulus generalization, see Honig & Urcuioli, 1981).

In the size domain, several studies have looked at pigeon’s discrimination performance when the area of the stimulus is varied. Jenkins, Pascal, and Walker (1958) trained pigeons to peck a 1.4-cm spot; later, the pigeons were presented with three increases and three decreases in the size of the spot. Although the pigeons exhibited significant generalization to the larger and smaller spots, there was also a systematic decrease in the rate of pecking as testing size varied from training size. Other studies involving modifications in the size of the stimuli have reported similar results. Pigeons showed significant generalization of discriminative performance to the same stimuli presented at novel sizes, but this generalization was not perfect; some decrement performance was also observed when size was changed (e.g., Lombardi & Delius, 1990; Pisacreta, Potter, & Lefave, 1984; Towe, 1954; Wildemann & Holland, 1973).

In all of this prior research on stimulus generalization with variations in size, rather simple stimuli were used: lines, circles, triangles, silhouettes, etc. It might be that, with items involving a small number of features, one dimension, such as size, is very salient, so that changes along that dimension render the new testing items quite dissimilar from the original training item. To further explore this issue, Peissig, Kirkpatrick, Young, Wasserman, and Biederman (2006) used a naming task to study pigeons’ object discrimination performance to both smaller and larger versions of line drawings of multi-part objects as well as shaded images of single-part objects which implied three-dimensionality. Nonetheless, even when more complex stimuli were used, the same pattern of performance was observed: significant generalization to new sizes, but systematic performance decrements as the new size deviated from the original size.

In Experiment 1 of the present study, we explored the effects of varying stimulus size by taking a different approach. We used a same-different task in which pigeons must discriminate two collections of several items that are either all identical to one another (Same arrays) or all nonidentical to one another (Different arrays). Both Same arrays and Different arrays appeared simultaneously on the screen and the pigeons had to choose one or the other depending on the background color of the screen (Castro, Kennedy, & Wasserman, in press; examples of trial displays are depicted in Figure 1). The items that composed the arrays were colorful objects that varied along many different dimensions, but they were all approximately the same size.

Once the pigeons mastered the same-different discrimination, we tested them with arrays containing the same item but in a variety of sizes, so that we could see if changes in size contributed to the birds' same-different discrimination. At issue was whether pigeons would treat arrays containing the same item in a variety of sizes as "same" or "different" arrays.

In addition to studying the effects of variations in the *size* of the stimuli in Experiment 1, we studied the effects of variations in the *location* of the stimuli in Experiment 2. During initial training of the conditional same-different task, we always grouped the icons in the center of the display. In Experiment 2, however, we also grouped the icons in other locations: the top, the bottom, the left, or the right portions of the array. Grouping the icons in different parts of the display might also affect pigeons' discrimination performance; when items are arranged in a novel fashion, it might prompt a decrement in discrimination performance, just as when other physical properties of the stimuli are varied. Spatial grouping was earlier found to exert reliable effects on pigeons' behavior in another same-different discrimination task (Wasserman, Young, & Nolan, 2000); but, Wasserman et al. presented only one array on each trial, thereby precluding the pigeon's simultaneously comparing one array with another, a possibly important factor.

Together, both Experiments 1 and 2 permitted us to see if same-different discrimination performance is affected by changes in the physical characteristics of the stimulus arrays. If pigeons acquire a general same-different concept, then these variations should have little or no effect on their discrimination behavior; but, if pigeons' learning of the same-different discrimination is strongly tied to the particulars of the training stimuli, then these variations should have large effects on their performance.

Experiment 1

Our birds had previously been trained to perform the conditional same-different discrimination involving 16-item Same and Different arrays simultaneously presented on the display screen. Depending on the color of the background, blue or red, the pigeons had to choose one or the other array (for example, "same" on blue trials and "different" on red trials). The pigeons had mastered this task to very high levels of accuracy (Castro et al., in press). In Experiment 1, we trained the pigeons with 7-item Same (identical icon, always the same size) and Different arrays (nonidentical icons, always the same size). All of the items were the same size within a trial; but, in order to familiarize the birds with the different sizes that were to be used during testing, the items could be of 7 different sizes across trials (see Figure 2 for examples of training arrays).

In the critical testing phase, we simultaneously presented Same-Uniform (identical icon, always the same size) and Same-Varied (identical icon in 7 different sizes) arrays on the screen (see Figure 3 for examples of testing arrays). If the 7 sizes of an icon were judged to be nonidentical, then the pigeons should behave as if a Same-Varied array is an array comprising 7 different icons. If this is the case, then the birds might choose the Same-Uniform array if the background color cued Same in training, but they might choose the Same-Varied array if the background color cued Different in training. This pattern of performance would be expected because, even though the icons are all the same, their sizes are different; displays of differently-sized items might then be treated as if they were actually Different arrays.

Alternatively, the birds might completely disregard any variations in the size of the icons and consider the differently-sized icons to be the same icon. If the 7 different sizes of an icon were judged to be identical, then the pigeons should treat both Same-Uniform and Same-Varied arrays as Same arrays. So, when the birds are cued to choose Same, they will see two Same arrays and they should choose one or the other randomly; when the birds are cued to choose Different, they will not see a Different array, so they should again choose randomly. Although this line of thinking suggests indiscriminate test responding, it might be possible to obtain a

meaningful disparity in reaction time; on Same trials there is always a “correct” stimulus (indeed, there are two), whereas on Different trials there is never a “correct stimulus,” perhaps prompting measurably faster reaction times in the first case than in the second.

Method

Subjects

The subjects were 4 feral pigeons maintained at 85% of their free-feeding weights by controlled daily feedings. The pigeons had earlier been trained to perform the conditional same-different discrimination task with 16-icon arrays (Castro et al., Experiment 1, in press). Later, we trained the birds with arrays containing 2, 4, 6, 8, 10, and 12 icons (Castro et al., Experiment 2, in press). In that prior project, all of the icons in the arrays were the same size (Size 3 in this experiment) and the pigeons performed at extremely high levels of accuracy.

Apparatus

The experiment used four $36 \times 36 \times 41$ cm operant conditioning chambers detailed by Gibson, Wasserman, Frei, and Miller (2004). The chambers were located in a dark room with continuous white noise. Each chamber was equipped with a 15-in LCD monitor located behind an AccuTouch[®] resistive touchscreen (Elo TouchSystems, Fremont, CA). The portion of the screen that was viewable by the pigeons was $28.5 \text{ cm} \times 17 \text{ cm}$. Pecks to the touchscreen were processed by a serial controller board outside the box. A rotary dispenser delivered 45-mg pigeon pellets through a vinyl tube into a food cup located in the center of the rear wall opposite the touchscreen. Illumination during the experimental sessions was provided by a houselight mounted on the upper rear wall of the chamber. The pellet dispenser and houselight were controlled by a digital I/O interface board. Each chamber was controlled by an Apple[®] eMac[®] computer. Programs to run this and the next experiment were developed in MatLab[®].

Stimuli and Experimental Design

A total of 72 color icons that were selected from an image database (Hemera Technologies Inc.) constituted the original icon pool. Each of the 72 icons was presented in invisible squares of 7 different sizes, ranging from 0.95 to 2.86 cm in width and from 0.95 to 2.86 cm in height. The actual size of the icon was as close as possible to the size of the square on which it was located; therefore, although icons within one size category were not exactly the same size (that was extremely difficult to accomplish given the nature of the stimuli), they were approximately the same size (examples can be examined in Figure 2). The 7 different sizes were created by reducing or enlarging the original training size ($1.59 \times 1.59 \text{ cm}$) that was designated as 100%. These original images were then transformed, so that there were two size decreases (60% and 80%) and four size increases (120%, 140%, 160%, and 180%). The scaling was relative, so that the aspect ratio of the altered stimuli remained the same as the original stimuli.

For any given Same array, a single icon was randomly chosen from the appropriate icon set and was then used to create an array of 7 identical icons. For any given Different array, 7 icons were randomly chosen from the icon set and then used to create an array of 7 nonidentical items. In training, all of the icons on a given trial were the same size; in testing, the size of the icons varied within a trial (see procedure below). The icons were randomly distributed to 7 of 9 possible locations in an invisible 3×3 grid composed of $3.4 \times 3.4 \text{ cm}$ cells (so, the size of each array was $10.2 \text{ cm} \times 10.2 \text{ cm}$). Thus, 7 of the 9 locations contained icons and 2 were blank. Each of the icons could be positioned in any part of each of the $3.4 \times 3.4 \text{ cm}$ cells. This distribution procedure resulted in disordered stimulus arrays in which vertical or horizontal alignment of the icons was precluded (Wasserman, Frank, & Young, 2002; Young & Wasserman, 2001b).

On each trial, two arrays, one Same and one Different, simultaneously appeared on the screen. The arrays were located on the left and the right side of the screen, 8 cm apart. Each of the arrays was circumscribed by a black border to emphasize their distinctiveness. For half of the trials the Same array was on the left and the Different array was on the right; the reverse was true for the other half of the trials.

Procedure

Training—A total of 25 days of training were given. Daily training sessions comprised 168 trials. At the start of a trial, the pigeons were presented with an orienting stimulus: a black cross on a white display in the middle of the screen. After one peck anywhere on the display, a red or blue background was shown on the screen for 1 s, after which the Same and Different displays appeared on the colored background. The pigeon's task was to peck directly at either the Same or the Different display. The color of the background served as a conditional cue signaling which display was correct. Half of the birds were required to peck at the Same display when the background color was blue and to peck at the Different display when the background color was red; the assignments were reversed for the other half of the birds.

On a given trial, all of the icons in each of the Same and Different arrays were the same size, so that the Same array would contain 7 identical icons of uniform size and the Different array would contain 7 nonidentical icons of the same uniform size. Therefore, there were seven type of trials, depending on the specific size that was shown; 24 trials of each specific size were shown in each training session. Examples of trial displays are shown in Figure 2.

Differential food reinforcement was used to encourage correct responses. If the choice response was correct, then food was delivered and a 5-s intertrial interval (ITI) ensued, during which the screen blackened and the pigeon awaited the next trial. If the choice response was incorrect, then there was no food and a timeout period began. The initial timeout duration was 5 s; it was increased by 2 s every day until the bird met criterion (85% correct for both Same and Different trials). After the timeout, correction trials were given until the correct response was made. Only the *first* report response of a trial was scored and used in data analysis. In addition, the time from the onset of the Same and Different displays to the pigeon's peck was recorded.

Testing—A total of 20 days of testing were given. Each testing session comprised 168 trials. Sessions began with 28 warm-up training trials followed by 140 additional trials of which 28 were randomly interspersed testing trials. On testing trials, a Same-Uniform array and a Same-Varied array were presented; the Same-Uniform array contained 7 identical icons all of the same size, whereas the Same-Varied array contained 7 identical icons in each of the 7 different sizes (see Figure 3). So, the Same-Varied arrays contained all of the 7 sizes and the Same-Uniform arrays contained just one of the sizes. There were 7 types of Same-Uniform arrays, depending on the specific size that was displayed. Each type of Same-Uniform array appeared four times in a testing session. Half of the testing trials cued the pigeons to make a "same" response, whereas the other half cued the pigeons to make a "different" response.

On training trials, only the correct response was reinforced; incorrect responses were followed by correction trials (differential reinforcement). On testing trials, *any* choice response was reinforced (nondifferential reinforcement); therefore, no correction trials were necessary.

In all of the reported tests of statistical significance, an alpha level of .05 was adopted.

Results

Training

Choice Responses—Accuracy levels were very high from the very beginning of the present training (overall, 89% on the first day), regardless of the introduction of icons of smaller and larger sizes. Nonetheless, we maintained the birds on training for 25 days, so that the pigeons would be familiarized with all of the different sizes. Figure 4 (left) illustrates the birds' mean percentage of correct responses during the last 5 days of this training phase. Overall, accuracy was very high, over 80%, regardless of the specific size of the items in the Same and Different arrays. Nonetheless, the percentage of correct responses seemed to decrease slightly at the smallest sizes: Size 2 and, especially, Size 1.

A 2 (trial type: Same vs. Different) $\times$ 7 (size) repeated measures analysis of variance (ANOVA) on the percentage of correct choice responses during the last 5 training days revealed a significant main effect of size, $F(6,18) = 11.71$, $MSE = 0.08$, confirming that accuracy varied depending on the specific size of the icons in the Same and Different arrays. No other main effects or interactions were significant. Tukey HSD analysis ($\alpha = .05$) revealed that the main effect of size was due to accuracy to Size 1 displays being lower than to any of the other displays; accuracy was not reliably different from Size 2 to Size 7.

Reaction Time—In all of the training and testing phases, we analyzed reaction time (RT) performance only on correct trials in order to minimize the contribution of any speed-accuracy tradeoffs which might cloud the interpretation of performance disparities. As well, all RTs longer than 20 s were assigned a maximum score of 20 s; in the last 5 days of training, the percentage of trials in which RTs exceeded 20 s was only 0.38% (see Ratcliff, 1993, for several different methods to deal with reaction time outliers). Finally, in order to normalize the distributions, RTs were subjected to log-transformation before statistical analyses.

As can be seen in Figure 4 (right), pigeons were slightly slower to choose the correct response when the arrays contained the smallest items ($M = 2,608$ ms), compared to arrays containing the intermediate, Size 4, or the largest, Size 7, items ($M = 2,274$ ms and $M = 2,349$ ms, respectively). A 2 (trial type: Same vs. Different) $\times$ 7 (size) repeated measures ANOVA revealed no significant effects or interactions. Despite of the tendency of the birds to be slowest with Size 1, no significant effect of size was observed [$F(6,18) = 1.65$, $MSE = 0.46$, $p = .19$].

Overall, pigeons' accuracy to all of the 7-item arrays was very high (scores ranging from 83% to 95%) and the birds were similarly fast to execute the correct response to all types of displays (RTs ranging from 2,230 ms to 2,608 ms). Although the smallest items were slightly more difficult to discriminate than the other item sizes, the Size 1 items were still highly discriminable for the pigeons (the mean accuracy score was 83%), so we included all 7 training sizes in the testing phase.

Testing

Choice Responses—As can be seen in Figure 5 (left), when the birds were presented with Same-Uniform (7 identical icons of the same size) and Same-Varied arrays (identical icons of 7 different sizes) simultaneously, they generally chose one or the other approximately 50% of the time regardless of the background color. The pigeons did not choose Same-Uniform when the background color cued "same" nor did they choose Same-Varied when the background color cued "different." Only when Size 1 icons in the Same-Uniform array were shown did the birds seem to prefer the Same-Varied array, but this preference occurred regardless of the color background.

A 2 (type: Same vs. Different) $\times$ 2 (trial: Training vs. Testing) $\times$ 7 (size) ANOVA on “same” choices revealed a main effect of type, $F(1,3) = 302.22$, $MSE = 0.99$, $p < .001$, and a Type $\times$ Trial interaction, $F(1,3) = 335.63$, $MSE = 0.78$, $p < .001$, showing that the birds chose “same” over “different” depending on whether it was a training trial or a testing trial: for training trials, “same” choices were very high on Same trials (91.4%) and very low on Different trials (12.4%), as expected because the birds had mastered the original same-different discrimination; for testing trials, “same” choices were very similar on Same- and Different-cued trials, 49.6% and 52.1%, respectively.

Binomial analysis showed that none of the testing displays differed significantly from chance level ($p > .05$), except for the Same-Uniform array containing all Size 1 icons when the pigeons were cued to choose “same” ($p < .01$). In this case, the birds tended to select the Same-Varied array, perhaps because they had to choose between a Same-Uniform array with all very small icons and a Same-Varied arrays with the same icon in various (mostly larger) sizes. Because the Size 1 icons seemed to be slightly more difficult for the pigeons to discriminate (Figure 4, left), perhaps the birds tended to avoid these arrays and select the other array with generally larger and more readily discriminable icons.

Thus, the choice report results suggest that, when the icons in a given array depicted the same icon but in different sizes (Same-Varied arrays), the birds did not perceive these arrays as being Different. Rather, the birds treated the Same-Uniform and Same-Varied arrays as Same training arrays, as if they both contained identical copies of the same icon. Thus, the pigeons randomly chose either the Same-Uniform array or the Same-Varied array, regardless of the color of the background.

Reaction Time—Figure 5 (right) shows the pigeons’ RT to make their choice response. Interestingly, RTs revealed that, when the color of the background cued Same, the birds were much faster to choose than when the color of the background cued Different. Although this tendency was present on training trials, the disparity between Same- and Different-cued trials was especially large on testing trials.

A 2 (type: Same vs. Different) $\times$ 2 (trial: Training vs. Testing) $\times$ 7 (size) ANOVA revealed a main effect of type, $F(1,3) = 22.31$, $MSE = 3.51$, showed that, overall, pigeons were faster when they were cued to choose Same ($M = 2,146$ ms) than when they were cued to choose Different ($M = 2,478$ ms). The Type $\times$ Trial interaction was significant as well, $F(1,3) = 62.90$, $MSE = 0.60$, indicating that the disparity between Same and Different depended on whether the pigeons were given training or testing trials. Critically, planned least squares comparisons showed that Same testing trials ($M = 1,937$ ms) were *faster* than Same training trials ($M = 2,174$ ms), $F(1,3) = 25.57$, $MSE = 0.60$, and that Different testing trials ($M = 2,997$ ms) were *slower* than Different training trials ($M = 2,406$ ms), $F(1,3) = 37.83$, $MSE = 0.60$.

These data support the idea that the birds were perceiving each of the two testing arrays, Same-Varied and Same-Uniformed, as Same. On Same-cued trials, the birds should be seeking the Same array. If they perceive the two arrays as both Same arrays, then they can rapidly choose one or the other, because either is what they are seeking. Therefore, RTs on these trials should be the fastest, even faster than on Same training trials where the initial look to the left or to the right is going to spot a Same array only half of the time. On Different-cued trials, however, the birds should be seeking the Different array, but there is none to be found, because both are perceived as Same arrays; this failure to find a Different array is likely to yield the increase in RTs with Different-cued trials.

Discussion

In Experiment 1, our pigeons effectively generalized their discrimination behavior to items that were presented in different sizes (as shown by their performance in the training phase; Figure 4). Moreover, when an array contained the same icon in 7 different sizes, the birds still considered the array to be Same. In short, the pigeons perceived one version of an icon to be the same as another version of the same icon shown in various highly discriminable sizes (as shown by their performance in the testing phase; Figure 5).

These data suggest that pigeons' visual recognition performance can show *size invariance*. These results accord with those of Young and Wasserman (2001b), in which pigeons were tested with arrays that contained a mixture of planar rotations of the icons at 0°, 90°, 180°, and 270°, after having learned to discriminate uniformly oriented Same and Different arrays. Varying the rotation of the icons within the array did not affect the pigeons' discriminative performance in Young and Wasserman's experiment; pigeons exhibited *orientation invariance* in that case.

The reader will by now have observed that the items within a specific size category, although they are *approximately* the same size, are not *exactly* the same size (the use of images of common multidimensional objects makes such equilibration extremely difficult). Thus, it could be argued that, in training, the pigeons might have been learning to discriminate sets of items of identical size (on Same trials) from sets of items of different sizes (on Different trials, because of the slight disparities in size among the multiple images that constituted each of our size categories). If that were the case, then the birds should have been especially inclined to choose the Same-Variied over the Same-Uniform arrays on Different-cued testing trials. But, we observed no such tendency.

The results of Experiment 1 therefore show a strong level of same-different discrimination behavior which is not easily disrupted by changes in the size of the stimuli. Expressed in Terrace's (1966) preferred terminology, the size dimension did not acquire stimulus control over the pigeons' same-different discrimination. In the next experiment, we studied the effects of variations in the location of the displayed stimuli, by manipulating the spatial organization of the items in the arrays to see if this property had acquired stimulus control.

Experiment 2

In our conditional same-different discrimination task, the icons were always distributed over all of the spatial regions in the array (see Figures 1, 2, and 3). In Experiment 2, the icons were grouped in other arrangements and locations as well, creating rectangular clusters that were located in the top, the bottom, the left, or the right portions of the display (Figure 6). Grouping the icons in different parts of the display might affect pigeons' discrimination performance; when the items are arranged in these novel patterns, pigeons might exhibit a generalization decrement, much as when other physical properties of the stimuli are modified. In addition, when the items are placed in the top or the bottom of the displays, they are horizontally aligned; when the items are placed in the left or the right of the displays, they are vertically aligned (see Figure 6). Some human visual perception studies suggest that our attentional mechanism is more likely to group horizontally- than vertically-oriented spatial layouts (e.g., Feng, Jiang, & He, 2007). If this is the case for birds as well, then it might be easier for the pigeons to perceive the sameness and differentness of the arrays when the items are horizontally rather than vertically arranged, so that better performance might be observed to the horizontal than to the vertical arrangements.

Also note that, in this task, both Same and Different arrays appear simultaneously on the screen and pigeons have to choose one or the other array conditional on the background color of the

screen. So, the pigeons might be looking at and comparing both arrays in order to choose the correct one. Grouping the icons in different parts of the displays might affect pigeons' stimulus comparison process. As a result of the different arrangements, the average distance between the items in the Same and Different arrays did vary (see below). It is conceivable that, the closer the items in the Same and Different arrays, the easier the comparison between the arrays will be and, therefore, the easier the discrimination; conversely, the farther the arrays of items, the more difficult the comparison between the arrays will be and the more difficult the discrimination.

But, it could be that the pigeons are not comparing the two arrays at all. This comparison process might be necessary as training unfolds; but, at this point, the birds had been performing the conditional same-different task for several months and their accuracy levels were very high. As we noted earlier, the pigeons must choose the Same or Different array depending on the color of the screen; that colored screen appears 1 s before the Same and Different arrays are shown. So, it is possible that the birds learn to anticipate the array that they have to choose when the screen turns blue or red; rather than waiting for the arrays to appear and to compare them, the pigeons might be seeking the correct array. If that is the case, then the distance between the items in the two arrays should have little or no effect on the pigeons' discrimination behavior.

Method

Subjects and Apparatus

The same 4 pigeons from Experiment 1 served as subjects in Experiment 2. The birds were maintained as before. The apparatus was the same as in Experiment 1.

Stimuli and Experimental Design

We used the same pool of 72 icons as in Experiment 1. All of the icons were the same size (1.59×1.59 cm), the original training size in Experiment 1. For any given Same array, a single icon was randomly chosen from the appropriate icon set and it was then used to create an array of 10 identical icons; for any given Different array, 10 icons were randomly chosen from the icon set and they were then used to create an array of 10 nonidentical items. The icons were located in 10 of 25 possible locations in an invisible 5×5 grid composed of 2×2 cm cells (so the size of each array was 10×10 cm) (Figure 6). Thus, 10 of the 25 locations contained icons and 15 were blank. Each of the 1.59×1.59 cm icons could be positioned in any part of each of the 2×2 cm cells, so that perfect alignment of the icons was precluded.

Procedure

Training—Before testing the birds with the different spatial arrays, we gave them training with standard 10-item arrays in which the icons were clustered in the middle of the display (see Figure 6, Center trials) for 3 days. The training procedure was nearly identical to that used in Experiment 1, except that each session contained a total of 200 trials: for half of them, the background was the color for reporting “same” and for the other half, the background was the color for reporting “different.”

Testing—A total of 10 days of testing sessions were given. Each testing session comprised 200 trials. Sessions began with 8 warm-up training trials followed by 192 additional trials of which 64 were training trials in which the icons were clustered in the middle of the display and 128 were randomly interspersed testing trials. There were 8 types of testing trials, depending on where the icons on the left and on the right array were located (see Figure 6). On half of the testing trials, the icons were horizontally placed: in both arrays on the top (H-Top); in both arrays on the bottom (H-bottom); in the left array on the top and in the right array on the bottom,

and in the left array on the bottom and in the right array on the top (we denote these two combinations as H-Top&Bottom). On the other half of the testing trials, the icons were vertically placed: on the right side of the left array and on the left side of the right array, so that the icons from both arrays were close to one another (V-Close); on the right side of both arrays or on the left side of both arrays (because the distance was the same in both cases, we denote these two combinations as V-SameSide); on the left side of the left array and on the right side of the right array, so the icons from both arrays were far from one another (V-Far). Half of the testing trials cued the pigeons to make a “same” response, whereas the other half of the testing trials cued the pigeons to make a “different” response. All of the trials were differentially reinforced.

Results

Training

Birds maintained very high discrimination performance during the 3 days of training with the 10-item arrays: overall, 98% on Same trials and 96.5% on Different trials.

Testing

Choice Responses—A preliminary ANOVA on choice responses with Grouping (Center vs. Horizontal vs. Vertical) and Type of trial (Same vs. Different) as factors failed to show a significant effect of Same-Different, $F(1,3) = 2.52$, $MSE = 0.15$, nor did this factor interact with Grouping, $F(6,18) = 1.04$, $MSE = 0.06$; so, for the sake of clarity, the Same-Different factor was not included in subsequent analyses.

As Figure 7 (left) shows, accuracy was very high for all of the different types of display trials. For the statistical analysis, we grouped the different types of trials in terms of their spatial arrangement: center, horizontal, and vertical. A one-way ANOVA on choice responses with Grouping (Center vs. Horizontal vs. Vertical) as a factor did not yield a significant main effect, $F(2,6) = 0.99$, $MSE = 0.11$. Accuracy to Horizontal and Vertical testing trials (95.5% and 94.5%, respectively) was as high as accuracy to Center training trials (96.1%). So, pigeons' discrimination behavior was not affected by the different arrangements of the icons in the arrays.

Reaction Time—We next examined pigeons' RTs to the different grouping arrangements. RTs longer than 20 s accounted for only 0.61% of scores and they were set to 20 s. As can be seen in Figure 7 (right), birds were faster when the icons were grouped in the middle of the array (the training value). Also, birds seemed to be slower when icons were horizontally arranged as compared to their being vertically arranged.

A one-way ANOVA on log RT with Grouping (Center vs. Horizontal vs. Vertical) as a factor yielded a main effect of Grouping, $F(2,6) = 32.49$, $MSE = 0.63$, $p < .001$. Tukey HSD comparisons showed that all the three different grouping arrangements differed from one another. Pigeons were the fastest when the icons were placed in the center (2,468 ms), slower when the icons were vertically arranged (2,705 ms), and even slower when the icons were horizontally arranged (3,069 ms). Further analysis disclosed that none of the horizontal trial types differed from one another and none of the vertical trial types differed from one another.

Examining all of the different type of trials (Figure 6), one can see that the distance between the groups of icons in the two arrays varied depending on the type of trial. We calculated the mean distance between the groups of icons; these scores ranged from 10.5 cm (V-SameSide) to 15.5 cm (H-Top, H-Bottom, V-Same Side) to 16.5 cm (H-Top&Bottom) to 20.5 cm (V-Far). A regression analysis showed that distance could not explain the variance in reaction times,

$R^2 = .0001$, $F < 1$. Indeed, the closest (V-Close trials) and the farthest (V-Far trials) inter-array distances yielded almost identical reaction times: 2,788 ms and 2,740 ms, respectively.

Discussion

Grouping the icons horizontally or vertically in different parts of the arrays did not affect the correctness of pigeons' discriminative performance; accuracy for testing trials remained as high as accuracy for training trials. Thus, no generalization decrement in accuracy was observed as a result of changes in the spatial arrangement of the icons. Nonetheless, the pigeons did notice the novel spatial arrangements because their reaction times were reliably longer when the icons were vertically and horizontally grouped compared to the more familiar clustering of icons in the center of the displays.

Those reaction times revealed other interesting results. First, the distance between the groups of items did not affect the birds' speed to choose. The most striking example is the comparison between V-Close (items were 10.5 cm apart) and V-Far trials (items were 20.5 cm apart)—the trials that displayed the shortest and longest distances between the groups of icons. Despite this large disparity, the pigeons were equally fast to choose on both type of trials. So, it seems that either pigeons' comparison between the arrays is not affected by distance or our manipulation of distance was not large enough to influence the pigeons' comparison. But, it might be that pigeons are not comparing the two arrays at all; it might be that when the color for Same appears they look for the Same array, whereas when the color for Different appears they look for the Different array. Our current results cannot distinguish between these options.

In most of the prior studies with multi-item arrays, only one Same or one Different array was presented at a time, so no direct comparison was possible; nonetheless, pigeons could successfully learn the task (e.g., Wasserman et al., 2000; Young & Wasserman, 1997; 2001b; 2002a; 2002b). These prior reports might support the idea that the pigeons were not comparing the arrays in our current experiments. However, we have observed much faster learning with the conditional discrimination task, in which the arrays are presented simultaneously (a mean of 1,584 trials in Castro et al., in press) than with the standard forced-choice task, in which the arrays are presented one at a time (a mean of 4,450 trials in Young & Wasserman, 1997). One reason for this learning advantage might be the simultaneous presentation of the arrays and, therefore, the possibility of comparing them (although there might be other reasons; see Castro et al., in press). So, although pigeons might not need to directly compare the Same and Different arrays, this does not mean that they do not do so if the tasks permits it.

Second, we did find an effect of the vertical-horizontal organization of the icons. Pigeons were faster to choose when the items were vertically arranged than when they were horizontally arranged. Vertical processing seems to be easier than horizontal processing for the pigeons. Incidental observations in an unpublished study from our laboratory suggest that the current vertical advantage might not be at all unusual. Lazareva and Wasserman (2006) trained pigeons to report whether two small target spots were on the same shape or on two different shapes that were presented on the screen. Initially, only one target spot appeared on one of the shapes and, after a number of pecks at this spot, a second target spot appeared, either on the same or on the different shape. Pigeons were faster to peck at this second spot when it was vertically located in relation to the first spot, regardless of its being on the same or on the different shape. It therefore seems that vertical processing is easier than horizontal processing for pigeons, perhaps because, for the birds, vertical head and/or body movements require less physical effort than horizontal movements.

General Discussion

The present pair of experiments studied the effects of stimulus size and spatial organization on pigeons' conditional same-different discrimination behavior. The results revealed virtually perfect stimulus generalization across various item sizes and spatial organizations; indeed, varying the size of the icons or their spatial layout in the array had almost no impact on the accuracy of pigeons' discriminative performance.

In our first experiment, choice responses showed that arrays of the same visual items were treated equivalently whether those arrays contained items of uniform size or items of varied sizes. Reaction times shed further light on the pigeons' behavior. Birds were faster to make their choice on Same-cued than on Different-cued trials, presumably because they were perceiving the two testing arrays, Same-Varied and Same-Uniformed, as Same. So, pigeons not only generalize their same-different discriminative performance to novel visual items (Wasserman et al., 1995; Young & Wasserman, 1997; Castro et al., in press) or to items presented in novel rotations (Young & Wasserman, 2001b), but also to items of smaller and larger sizes as well.

Nonetheless, prior investigations have reported decrements in performance when stimuli were presented at different novel sizes (e.g., Jenkins et al., 1958; Lombardi & Delius, 1990; Pisacreta et al., 1984; Peissig et al., 2006; Towe, 1954; Wildemann & Holland, 1973). In all of those prior studies, the stimuli were relatively simple and their number was relatively small. It might be that the use of a large pool of multidimensional and colorful items made the size dimension less relevant for the birds, so that size did not acquire control over the birds' discriminative performance; therefore, nearly perfect generalization could be observed to novel testing stimuli. This finding may have important implications for size invariance studies: the richer and more complex the stimuli that are presented to the animals, the more robust the generalization might be to the same stimuli presented in both smaller and larger sizes.

Our second experiment showed that novel spatial organizations of the visual items in the arrays yielded accuracy scores that were nearly as high as when the items were grouped in the familiar center location; indeed, virtually complete generalization to novel spatial layouts was observed in this experiment.

Interestingly, although neither horizontal nor vertical arrangements affected pigeons' choice accuracy, they did have an effect on pigeons' speed to choose the correct array. Pigeons were faster to make their choice when the items were vertically arranged than when they were horizontally arranged. As noted above, unpublished data from our laboratory also divulged a similar disparity between vertical and horizontal processing: after pecking one target spot, pigeons were faster to peck a second spot that was vertically, rather than horizontally, aligned with the first spot (Lazareva & Wasserman, 2006). Curiously, several human visual discrimination studies have found the opposite tendency: better performance when stimuli are horizontally, rather than vertically, aligned (e.g., Feng et al., 2007; Westheimer, 2005). This horizontal versus vertical asymmetry in humans might be due to our extensive reading experience, in which letters and words are normally horizontally aligned. Or, more generally, it could be that our visual environment tends to extend horizontally rather than vertically, so that stimuli in the horizontal axis are preferentially attended (Pan & Eriksen, 1993).

Pigeons' possible preference for vertically arranged stimuli surely requires further study. As mentioned above, it could be that, in our experimental task, vertical movements require less physical effort than horizontal movements. Also, it could be that our displays are very large from the pigeon's point of view making it is easier for the bird to focus on the vertical axis when they have to attend to an unusually large portion of the visual field. Or it might be that other ecological constraints are influencing the pigeon's tendency to faster processing of

vertically aligned stimuli. For example, for flying birds, objects requiring attention appear both above the horizon (when flying) and below the horizon (when walking), thereby enhancing the relevance of the vertical axis for the birds.

Finally, our results add to growing evidence that pigeons exhibit, at the very least, rudiments of abstract same-different conceptualization (e.g., Cook & Wasserman, 2006; Katz, Wright, & Bodily, 2007; Young & Wasserman, 1997; Wasserman & Young, in press). Nearly 25 years ago, Herbert Terrace (1985, p. 126) raised this telling question:

Now that there are strong grounds to dispute Descartes' contention that animals lack the ability to think, it is appropriate to determine just how an animal does think. In particular, how does an animal think without language?

We are still far from having a satisfactory answer to Terrace's question. But, we are steadily advancing in that direction. We now know that language is not necessary for animals to learn a relational concept like same-different, what some theorists deem to be the very basis of our mental structure and thinking (James, 1980), and the first step toward higher abilities like logical inference and analogical reasoning. But, if animals' same-different learning is not mediated by language, then how do they do it?

Young and Wasserman (1997) presented pigeons with 16-item arrays which comprised *mixtures* of identical and nonidentical icons; they observed that the birds exhibited a linearly increasing tendency to report "different" as the proportion of nonidentical icons increased. Young and Wasserman concluded that the pigeons did not *categorize* the stimuli into "same" versus "different," but that they *dimensionalized* the stimuli into "low variability" versus "high variability" (see also, Wasserman et al., 2002; Wasserman & Young, in press; Young & Wasserman, 2001b; 2002a; 2002b).

Later research revealed that this dimensional treatment of the same-different task was not a peculiarity of birds. Baboons responded in a similar way (Wasserman, Fagot, & Young, 2001); indeed, even a *minority* of college students also treated the task as a dimensional discrimination (Young & Wasserman, 2001a). Moreover, reaction time performance suggested that the *majority* of college students were sensitive to perceptual variability (Young & Wasserman, 2001a; Castro, Young, & Wasserman, 2006). All organisms even humans, who are capable of using language may rely on variability when solving a same-different discrimination; so, the perception of variability may truly be the substrate of abstract conceptual thinking (Wasserman, Young, & Cook, 2004).

Thus, abstract concepts may result from perceptual processing, a proposition which has been suggested from researchers of human cognition as well (e.g., Goldstone & Barsalou, 1998). A better understanding of the interplay between perception and abstraction in animal and human cognition will help us to determine how animals and humans think with and without the participation of language.

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Figure 1.

Example of the two types of trials in Castro, Kennedy, and Wasserman (in press). The color of the background indicates whether the pigeons must choose the Same or the Different array. For example, in the case of the red background, the correct choice was the Same array, whereas in the case of the blue background, the correct choice was the Different array.

Training

Figure 2.

Examples of some of the training arrays used in Experiment 1. One Same (identical icon, always the same size) and one Different (seven nonidentical icons, always the same size) array were simultaneously presented on the screen. In the actual experiment, the arrays could appear either on a red or a blue background.

Testing

Figure 3.

Examples of some of the testing arrays used in Experiment 1. One Same-Uniform array (identical icon, always the same size) and one Same-Varied array (identical icon in seven different sizes) were simultaneously presented on the screen. In the actual experiment, the arrays could appear either on a red or a blue background.

Figure 4.

Mean accuracy during the last 5 training days in Experiment 1 for all the 7 different sizes. Left, mean percentage of correct responses. Right, log-transformed reaction time (RT) to choose the correct response. Error bars indicate the standard error of the means.

Figure 5.

Mean accuracy as a function of the size of the items in the Same-Uniform array across the 20 testing sessions in Experiment 1. Left, mean percentage of “same” responses. Right, log-transformed reaction time (RT) to choose either “same” or “different.” Error bars indicate the standard error of the means. The dashed line indicates the chance level of performance.

Figure 6.

Examples of the training (Center) and testing (H-Bottom, H-Top, H-Top&Bottom, V-Close, V-Far, and V-SameSide) arrays used in Experiment 2. For H-Top&Bottom arrays, on half of the trials the items in the left array were located on the top and the items in the right array were located on the bottom, and the reverse was true for the other half of the trials. For V-SameSide arrays, on half of the trials the items in both arrays were located on the left, and on half of the trials they were located on the right. In the actual experiment, the arrays could appear either on a red or a blue background.

Figure 7.

Mean accuracy as a function of the grouping of the items across the 10 testing sessions in Experiment 2. Left, mean percentage of correct responses. Right, log-transformed reaction time (RT) to choose the correct response. Error bars indicate the standard error of the means.