WHOLE REVERSAL VERSUS PARTIAL REVERSAL ADVANTAGE EFFECT ON SAME-DIFFERENT DISCRIMINATIONS IN RATS

ESHO NAKAGAWA
Kagawa University

The present experiment has examined a whole reversal versus partial reversal advantage effect on same-different discrimination using a whole-partial reversal procedure in rats. This experiment was a limited parameter study of the reinforcer density variable from Phase 1 training to Phase 2 reversal. Rats were trained to criterion on 12 same-different tasks (6 same and 6 different tasks) and then given reversal training on either a whole reversal condition (W), in which all of the 12 tasks were reversed, a partial reversal-10-condition (P-10), in which 5 same and 5 different tasks were reversed, a partial reversal-5-condition (P-6), in which 3 same and 3 different tasks were reversed, or a partial reversal-2-condition (P-2), in which one same and one different task were reversed. Group W reversed faster than the other three partial groups. Group P-2 reversed faster than Group P-6, which in turn reversed faster than Group P-10. These results provided evidence that rats formed functional stimulus classes during initial same-different discrimination training.

There are many studies on a whole reversal versus partial reversal advantage effect in pigeons and rats using a whole-partial reversal procedure in either two concurrent discrimination learning tasks (Delius, Ameling, Lea, & Staddon, 1995; Dube, Callahan, & MacIlvane, 1993; Nakagawa, 1978, 1986, 1992, 1998, 1999a, 2000b, 2001) or matching-(or nonmatching)-to-sample discrimination learning tasks (Nakagawa, 1999b, 2000a; Vaughan, 1988; Zentall, Sherburne, Steirn, Randall, Roper, & Urcuioli, 1992; Zentall, Steirn, Sherburne, & Urcuioli, 1991). In the whole-partial reversal procedure, animals were trained with many discrimination tasks to criterion in the initial training, and they were transferred to either a whole reversal condition, in which all tasks were reversed, or a partial reversal condition, in which only half of the tasks were reversed but the remaining tasks were not reversed. These studies

Requests for reprints should be sent to E. Nakagawa, Department of Psychology, Kagawa University, 1-1 Saiwai-Cho, Takamatsu, Kagawa, 760-8522, Japan. (E-mail: esho@ed.kagawa-u.ac.jp).
made it clear that rats and pigeons learned the whole reversal more rapidly than the partial reversal either after overtraining in two concurrent discriminations or matching- (or nonmatching)-to-sample discriminations (a whole reversal versus partial reversal advantage effect). There are two separate definitions of a stimulus class: The first one pertains to functional equivalence, and the second pertains to the control of a specific response by a member of stimuli. Goldiamond (1962) argues that both are necessary for a set of stimuli to be considered a stimulus class. The whole reversal versus partial reversal advantage effect indicated that animals such as rats and pigeons formed an untrained, emergent relationship between unrelated discriminative stimuli. Thus, this whole reversal versus partial reversal advantage effect has been taken as evidence for the development of stimulus classes in these animals. See also Zentall (1998) and Zentall et al. (1991). Zentall et al. (1991) have suggested that faster whole reversal than partial reversal is based on the difference in detectability of change in reinforcement across phases, between whole and partial reversals. For the birds of the whole reversal, there is a larger, and thus probably a more detected, change in the conditions of reinforcement from Phase 1 training to Phase 2 reversal than the birds for the partial reversal. For the whole reversal, responding on the basis of the rule acquired in the original learning results in nonreinforcement on all trials. On balance, for the partial reversal, responding on the basis of the rule acquired in the original learning still results in reinforcement on half of the trials (Zentall et al., 1991, p. 200; Zentall, 1998, p. 366). The whole reversal versus partial reversal advantage effect may be attributable to the discriminability of the change in reinforcement contingencies at the time of reversal.

Nakagawa (1999b) offered evidence for positive transfer between two concurrent and matching- (or nonmatching)-to-sample discriminations in rats. In Experiment 1 of Nakagawa (1999b), rats were trained to criterion (Group NOT) or were overtrained (Group OT) on two concurrent discriminations. Subsequently, Group OT learned matching (or nonmatching) tasks more rapidly than did Group NOT. In Experiment 3 of Nakagawa (1999b), two groups of rats were trained on matching (or nonmatching) tasks in Phase 1, and then given concurrent discrimination training in Phase 2, followed by either whole or half reversal training (Groups Matching and Nonmatching) in Phase 3. Another group (Group Control) received a pseudo-discrimination in Phase 1, in which animals were given the same training as that in the matching group on the odd training day and the same training as that in the nonmatching group on the even training day, followed by the same training in Phases 2 and 3 as in Groups Matching and Nonmatching. In Groups Matching and Nonmatching, rats learned the whole reversal more rapidly than the half reversal. But the opposite result was observed in Group Control.

Nakagawa (2000c) provides evidence for positive transfer of learning between same-different and matching- (or nonmatching)-to-sample discriminations in rats. In Experiment 3 of Nakagawa (2000c), rats trained
with matching (or nonmatching) tasks facilitated subsequent same-different discriminations, relative to rats given either a simultaneous discrimination or a pseudo-discrimination training with matching (or nonmatching) tasks. In Experiment 4 of Nakagawa (2000c), rats trained with the same-different discriminations facilitated subsequent matching (or nonmatching) tasks, relative to rats given either a position discrimination or a pseudo-discrimination training with the same-different tasks.

These findings of Nakagawa (1999b, 2000c) suggested that these transfer effects reported in these studies were governed by the same mechanism for the formation of associations between stimuli. That is, these findings of Nakagawa (1999b, 2000b) suggested that the same mechanism governed the formation of associations between stimuli in either two concurrent, matching- (or nonmatching)-to-sample or same-different discriminations in rats. A specific question, however, remains. Do rats form stimulus classes (i.e., functional stimulus classes) between stimuli in same-different discriminations? It was not clear from the past research, however, whether rats formed functional stimulus classes between stimuli in same-different discriminations. This was a very important and fundamental issue in behavior analysis in studying stimulus classes formation in pigeons and rats. This problem had received far too little experimental attention in same-different discriminations.

Many studies have reported that pigeons and monkeys formed same and different concepts. These studies could be classified into three categories with respect to kinds of task used: The first type of the research involved the classification of only two visual items as same or different (e.g., Edwards, Jagielo, Zentall, & Hogan, 1983; Santiago & Wright, 1984; Wright, Santiago, & Sands, 1984; Wright, Santiago, Sands, Kendrick, & Cook, 1985; Wright, Santiago, Urquioi, & Sands, 1983). The second type has used multielement visual displays (e.g., Astley & Wasserman, 1998, 1999; Wasserman, Hugart, & Kirkpatrick-Steger, 1995; Young & Wasserman, 1997; Young, Wasserman, & Garner, 1997). The third type has used multielement texture stimulus (or multidimensional same-different texture visual stimuli) (e.g., Cook, Cavoto, & Cavoto, 1995, 1996; Cook, Katz, & Cavoto, 1997; Cook & Wixted, 1997).

These studies on same and different concepts formation mentioned above did, however, not make it clear that animals formed functional stimulus classes between stimuli. Thus, the present study attempted to demonstrate functional stimulus classes formation between stimuli in same-different discriminations and at the same time, to investigate the effect of the reinforcement density on the whole reversal versus partial reversal advantage effect using the whole-partial reversal procedure. In order to achieve these aims, the present experiment conducted a limited parametric study of the reinforcement density variable from Phase 1 training to Phase 2 reversal in same-different discriminations. That is, in the present study, rats were trained to criterion on 12 same-different discrimination problems in Phase 1 training. After completing Phase 1 training, rats were trained to reach a criterion in Phase 2 reversal under
some one of the four reversal conditions of a whole, a partial-10, a partial-6, and a partial-2. All 12 discrimination problems were reversed under the whole reversal condition. Of the 12 problems, 10, say 5 identical stimulus sets and 5 nonidentical stimulus sets, were reversed under the partial-10 reversal condition. Of the 12 problems, 6, say 3 identical stimulus sets and 3 nonidentical stimulus sets, were reversed under the partial-6 reversal condition. Of the 12 problems, 2, say 1 identical stimulus set and 1 nonidentical stimulus set, were reversed under the partial-2 reversal condition. The expectation according to the reinforcement density view proposed by Zentall et al. (1991) and Zentall (1998) was as follows: Rats in the whole reversal condition learned reversal faster than those in the partial-10 reversal condition, which in turn learned reversal faster than those in the partial-6 reversal condition, which in turn learned reversal faster than those in the partial-2 reversal condition. Reinforcer density changed from 100% to 83.3% from Phase 1 training to Phase 2 reversal in the partial-2 reversal condition, reinforcer density changed from 100% to 50% from Phase 1 training to Phase 2 reversal in the partial-6 reversal condition, reinforcer density changed from 100% to 16.7% in the partial-10 reversal condition, and reinforcer density changed from 100% to 0% from Phase 1 training to Phase 2 reversal in the whole reversal condition.

Alternatively, the expectation according to Nakagawa’s findings (2000a) is that rats in the whole reversal condition should learn their reversal faster than those in the other three partial reversal groups of P-10, P-6, and P-2, and that rats in the partial-2 reversal condition should learn their reversal faster than those in the partial-6 reversal condition, which in turn should learn their reversal faster than those in the partial-10 reversal condition. Because if rats in partial reversal groups had dissociated functional stimulus classes formed during Phase 1 training to resolve their partial reversal in Phase 2 reversal, 12 tasks would be independent of one another in reversal learning. Thus, rats in the partial-2 reversal condition had only 2, rather than 6, associations to relearn, and rats in the partial-6 reversal condition had 6, rather than 10, associations to relearn that rats in the partial-10 reversal condition had.

Method

Subjects

Twenty experimentally naive male Sprague-Dawley rats were used. They were about 210 days old, with an initial average body weight of 419 g. The animals were handled for 5 min a day for 12 days, and were maintained on a daily 2-hr feeding schedule prior to the experiment. The amount of food in the daily ration was gradually reduced until the body weight of each animal reached 80% of the baseline weight at the start of the experiment. Water was always available for the animals in their individual home cages. The animals were maintained on a 5-hr light, 19-hr dark cycle with lights off at 9:00 p.m. Experimental sessions took place during the light phase of the cycle.
Apparatus

An experimental chamber (15 cm high, 22.5 cm wide, and 15 cm long) was used in magazine training and lever-press training; it contained a square display screen with sides of 5 cm, which was 5 cm above the floor, and one lever beside the screen, which was a 5-cm x 3-cm rectangle and 5 cm above the floor. There was a food tray on the opposite wall of the lever, into which a milk pellet was delivered from a feeder when

Figure 1. Diagram of the automatic T maze used in Experiments 1 and 2 (Units = centimeter). (CC = choice chamber; CS = comparison stimulus; FT = food tray; GD = guillotine door; H = hurdle; L = lever; PB = photobeam; PG = photoelectric gate; RW = runway; SB = start box; SS = sample stimulus).
animals pressed the lever. An automatic T maze was used (Figure 1; see Experiment 2 in Nakagawa, 1993a, 1999b). The apparatus was lit throughout the experiment by a 10-W fluorescent lamp suspended 40 cm above the top of a choice chamber. The apparatus consisted of a runway (30 cm high, 12 cm wide, and 42 cm long) with a start box (30 cm high, 12 cm wide, and 25 cm long) and a choice chamber (30 cm high, 56 cm wide, and 12 cm long). A hurdle (3 cm high, 12 cm wide, and 5 cm long) was located at the end of the runway to make animals attend to a sample stimulus. The walls of the apparatus were medium-gray Plexiglas and the ceiling was clear Plexiglas. The start box had a food tray in the center of the end wall, into which a milk pellet was delivered from a feeder when animals made a correct response. The choice chamber contained three display screens, each 12 cm square, which were 10 cm above the floor and 5 cm apart from edge to edge. All stimuli were shown behind these Plexiglas screens by means of a computer monitor (Sharp Hi-Vision 32C-HD90). The computer monitor was located 9 cm behind the center screen at its center and 10 cm behind the two side screens at their outer edges (the difference being caused by the slight convex curvature of the face of the monitor). There were two response levers in the choice chamber, each 4 cm square and 9 cm above the floor. These levers were located below the center of the side screens. A guillotine door opened and closed automatically to control access to the start box. Whenever animals interrupted a photobeam at the exit of the start box, which was located 3 cm from the guillotine door, stimuli were automatically shown behind Plexiglas screens. The animals were then allowed to approach and press a response lever, whereupon they had to return to the start box. As they approached they interrupted a photoelectric gate located 5 cm from the end wall in the start box, and the guillotine door closed automatically behind the animals. After 10 sec the guillotine door opened automatically for the start of the next trial. The programming of events and data collection were carried out on-line using a laboratory computer. Sound masking was provided by white noise from a blower fan (50 db).

**Stimuli**

The stimulus was shown behind the center Plexiglas screen and medium-gray stimuli were shown behind both of the side Plexiglas screens by means of the computer monitor. The stimuli disappeared when animals pressed a response lever. Six stimuli were used: a circle (with an area of 21.0 cm²), a triangle (with an area of 21.5 cm²), an isosceles trapezium (with an area of 21.0 cm²), a cross (➕, with an area of 22.0 cm²), figure (with an area of 21.0 cm²), and figure (with an area of 21.0 cm²). A figure was black and the ground was white. These stimuli were the ones first used by Nakagawa (1979). The circle was referred to as A, triangle as B, isosceles trapezium as C, cross as D, figure as E, and figure as F in the present experiment. An identical stimulus (i.e., same task) consisted of two same stimuli (i.e., AA, BB, CC, DD, EE, FF). A nonidentical stimulus (i.e., different task) consisted of two different stimuli (i.e., CD, CE, EF, FA, AB, BD) as in Table 1 (see also Figure 5 in Nakagawa, 1993a).
Table 1
Order of Trials of a Same and a Different Problem and Random Presentation Sequences of Stimuli Used in Both Phases 1 and 2

<table>
<thead>
<tr>
<th>Random Sequence 1</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+A</td>
<td>A+</td>
<td>MM</td>
<td>AM</td>
<td>MM</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
</tr>
<tr>
<td>L</td>
<td>L</td>
<td>L</td>
<td>R</td>
<td>(L)</td>
<td>L</td>
<td>R</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
</tr>
<tr>
<td>Random Sequence 2</td>
<td></td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
</tr>
<tr>
<td>L</td>
<td>R</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
</tr>
<tr>
<td>Random Sequence 3</td>
<td></td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
</tr>
<tr>
<td>R</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Random Sequence 4</td>
<td></td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
</tr>
<tr>
<td>L</td>
<td>R</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
</tr>
<tr>
<td>Random Sequence 5</td>
<td></td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
<td>MM</td>
</tr>
<tr>
<td>R</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Random Sequence 6</td>
<td></td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
</tr>
<tr>
<td>L</td>
<td>R</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
</tr>
<tr>
<td>Random Sequence 7</td>
<td></td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
</tr>
<tr>
<td>L</td>
<td>R</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
</tr>
<tr>
<td>Random Sequence 8</td>
<td></td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
<td>A+</td>
</tr>
<tr>
<td>L</td>
<td>R</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
<td>(L)</td>
</tr>
</tbody>
</table>

Procedure

Magazine training and shaping of lever press. All animals received magazine training and lever-press training in the experimental chamber for 5 days prior to the beginning of pretraining. In this training stage, animals were trained to press the lever and return to the food tray on the wall opposite to the lever to obtain a milk pellet which was delivered from a feeder in the experimental chamber. On the last day all animals pressed the lever at least 50 times for 10 min a day.

Pretraining. After completing both magazine training and lever-press shaping, animals were given pretraining for 8 days prior to the beginning of the training phase until they pressed the lever at least 15 times per day on each side in the automatic T maze. Animals were given training to press the right side lever 15 times on an odd pretraining day and to press the left side lever 15 times on an even pretraining day. That is, animals were given training such that, after opening the guillotine door, they ran down the runway, pressed a response lever, and returned to the start box. After completing pretraining, all animals returned to the start box in less
than 2 sec after pressing a response lever. A medium-gray stimulus was rear-projected onto the screen during shaping and onto each of three screens during pretraining.

**Training.** A trial in this experiment is defined as a response-stimulus sequence, beginning when animals leave the start box after opening the guillotine door and continuing as they run down the runway, press a response lever, and return to the start box.

**Phase 1 original same-different discrimination training.** Animals were initially trained for 12 trials a day with 12 same-different tasks, in which they were given a same task using an identical stimulus on six trials and a different task using a nonidentical stimulus on the other six trials in random order within each session. Training continued until a criterion had been reached of 10 or more correct trials out of a possible 12 over 2 successive days. A noncorrection training method was used. The stimuli disappeared when animals pressed an incorrect lever. The animals were, however, allowed to return to a correct response lever and press it, and they were given a reward. Half of the animals were required to press the right lever on the same task trials (i.e., AA, BB, CC, DD, EE, FF) and to press the left lever on the different task trials (i.e., AB, BD, CD, CE, EF, FA). The remaining animals were required to press the left lever on the same task trials and to press the right lever on the different task trials. The order of trials with the two tasks of same and different followed eight predetermined random sequences (see Table 1). The trial sequences in Table 1 were randomized across sessions. Animals were given one 45-mg milk pellet accompanied by a click of the feeder when they made a correct response. The programmed intertrial interval was 10 sec.

**Phase 2 reversal learning.** After completing Phase 1 original same-different learning, animals were divided into four subgroups (whole reversal, partial-10 reversal, partial-6 reversal, and partial-2 reversal), matched with respect to the number of days to criterion. The animals of Group Whole (i.e., W) were run under a “whole” reversal condition, in which all 12 same and different tasks were reversed. That is, animals trained to press the right lever on same task trials and to press the left lever on different task trials during Phase 1 original training were required to press the left lever on same task trials and to press the right lever on different task trials. The animals of Group Partial-10 (i.e., P-10) were run under a “partial-10” reversal condition, in which both five same tasks of AA, CC, DD, EE, and FF, and five different tasks of CD, CE, DB, EF, and FA were reversed but not for one remaining same task and one different one such as BB, AB. That is, animals trained to press the right lever on same task trials of AA, CC, DD, EE, and FF, and to press the left lever on different task trials of BD, CD, CE, EF, and AF during Phase 1 original training were required to press the left lever on the same task trials and to press the right lever on the different task trials, but they were required to press the right lever on the remaining same task trial and to press the left lever on the remaining different task trial as well as during Phase 1 original training. The animals of Group Partial-6 (i.e., P-6) were run under a “partial-6” reversal condition, in
which three same tasks of AA, DD, and EE, and three different tasks of BD, CE, and AF were reversed but not for three remaining same tasks and three remaining different ones such as BB, CC, FF, CD, EF, and AB. The animals of Group Partial-2 (i.e., P-2) were run under a “partial-2” reversal condition, in which one same task (AA) and one different task (AB) were reversed but not for five remaining same tasks and five different ones such as BB, CC, DD, EE, FF, BD, CD, CE, EF, and AF. Other aspects of the procedure were the same as those during the original training.

Results

The mean number of days to reach criterion in Phase 1 of the experiment was as follows: 73.00 (SD = 9.27) for Group W, 70.60 (SD = 6.02) for Group P-10, 71.20 (SD = 6.27) for Group P-6, and 70.60 (SD = 7.12) for Group P-2. A statistical analysis performed on the number of

![Figure 2. Mean days and SEMs to criterion for each group in Phase 2 reversal as a function of types of reversal learning.](image)
days to criterion revealed no significant difference in the rate of learning among these four groups, $F(3, 16) < 1$.

Acquisition of Phase 2 reversal by each partial reversal group (P-10, P-6, and P-2) was compared with acquisition of the corresponding whole reversal group. These data are illustrated in Figure 2. An ANOVA using group (W vs. P-10 vs. P-6 vs. P-2) performed on the number of days to criterion data indicated significant between-group difference, $F(3, 16) = 73.36, p < .001$. A Scheffé test was run to analyze differences in the number of days to criterion among these four groups: Group W learned the reversal more rapidly than either Group P-10, $F(1, 16) = 212.36, p < .001$; Group P-6, $F(1, 16) = 80.53, p < .001$; or Group P-2, $F(1, 16) = 38.86, p < .001$. Group P-2 also learned the reversal more rapidly than either Group P-10, $F(1, 16) = 69.53, p < .001$; or Group P-6, $F(1, 16) = 7.51, p < .05$. Group P-6 learned the reversal faster than Group P-10, $F(1, 16) = 31.35, p < .001$.

In order to examine further whether or not all of the same and different stimuli functioned as equivalence classes, accuracy to stimuli with unchanged and changed reinforcement contingencies during Phase 2 reversal in each partial group were analyzed. Accuracy to stimuli with changed (i.e., reversed) and unchanged (i.e., unreversed) reinforcement contingencies during Phase 2 reversal in each partial group were plotted in Figures 3, 4, and 5. Each of Figures 3, 4, and 5 illustrated mean choice accuracy to stimuli with unreversed and reversed reinforcement contingencies for each animal in each partial group as a function of a block of 48 trials (i.e., 4 day trials). The inspection of Figures 3, 4, and 5 revealed that accuracy to stimuli with unreversed reinforcement contingencies dropped in all rats and the overall accuracy scores were lower in each partial group, relative to accuracy of response during original criterion days. Group mean rate of correct response on unchanged tasks during Phase 2 in Group P-2 was 61.5%, that of Group P-6 was 57.7%, and that of Group P-10 was 57.7%, whereas accuracy scores of response on the corresponding tasks during original criterion days of Group P-2 were 84.2%, those of Group P-6 were 84.2%, and those of Group P-10 were 85.0%. Accuracy scores to unreversed stimuli were significantly lower than those on corresponding stimuli during the 2 days of criterion in Phase 1 training in Group P-2, $\chi^2(1) = 24.93, p < .001$; in Group P-6, $\chi^2(1) = 32.36, p < .001$; and in Group P-10, $\chi^2(1) = 33.83, p < .001$. Percentage of correct response on unchanged tasks on the first block in Phase 2 in Group P-1 was 58.4%, that of Group P-6 was 45.8%, and that of Group P-10 was 45.0%. Figures, 3, 4, and 5 revealed that performance on the stimuli with changed reinforcement contingencies (i.e., reversed tasks) had influence on performance to the stimuli with unchanged reinforcement contingencies (i.e., unreversed tasks) for each rat in all groups during Phase 2 shift. That is, rats’ accuracy of response on unreversed tasks in Block 1 dropped below 60% correct level except for both No. 23 in Group P-2 (70% correct) and No. 104 in Group P-10 (62.5% correct).
Figure 3. The panel shows mean choice accuracy to reversed stimuli and unreversed stimuli for the 5 individual rats in Group P-2 (21, - , - , and 25) during Phase 2 reversal as a function of block of 4 days (48 trials) (R means the reversed stimuli, and NR means the unreversed stimuli. CR means the 2 days of criterion in Phase 1 training). A last block for each rat of 22, and 25 consisted of 1 day. A last block for each rat of 21, and 23 consisted of 3 days.
Figure 4. The panel shows mean choice accuracy to reversed stimuli and unreversed stimuli for the 5 individual rats in Group P-6 (61, -.-, and 65) during Phase 2 reversal as a function of block of 4 days (48 trials) (R means the reversed stimuli, and NR means the unreversed stimuli. CR means the 2 days of criterion in Phase 1 training). A last block for each rat of 62, 63, and 64 consisted of 1 day. A last block for 1 rat (61) consisted of 3 days.
Figure 5. The panel shows mean choice accuracy to reversed stimuli and unreversed stimuli for the 5 individual rats in Group P-10 (101, 102, 103, and 105) during Phase 2 reversal as a function of block of 4 days (48 trials) (R means the reversed stimuli, and NR means the unreversed stimuli. CR means the 2 days of criterion in Phase 1 training). A last block for 1 rat (104) consisted of 1 day. A last block for 1 rat (103) consisted of 2 days. A last block for 1 rat (101) consisted of 3 days.
Discussion

Group W mastered their reversal more rapidly than did either Group P-10, Group P-6, or Group P-2 (the whole reversal versus partial reversal advantage effect). This finding was in line with the expectation from the discrimination theory of the whole reversal versus partial reversal advantage effect postulated by Zentall et al. (1991) and Zentall (1998) that the advantage effect of the whole reversal over the partial reversals might be attributed to the discriminability of the change in reinforcement contingencies at time of reversal. This whole reversal versus partial reversal advantage effect demonstrated that rats formed functional stimulus classes between the stimuli in same-different discriminations. This functional stimulus classes formation was also supported by results of accuracy scores data on an unchanged and changed task (see Figures 3, 4, and 5). Figures 3, 4, and 5 indicated that after completing Phase 1 training, performance on the 12 same-different discriminations was no longer independent. That is, results of Figures 3, 4, and 5 dramatically indicated that rats formed functional stimulus classes between stimuli in Phase 1 training. These findings of the present experiment indicated that stimuli became functionally equivalent during same-different discrimination learning.

The most interesting findings were that, under partial reversal conditions, Group P-2 reversed faster than Group P-6, which in turn reversed faster than Group P-10. These findings were consistent with the findings of matching- (or nonmatching)-to-sample discriminations using 12 different stimulus sets of Experiments 1 and 2 of Nakagawa (2000a). These findings indicated that rats learned the shift from 100% to 83.3% in reinforcement density from Phase 1 training to Phase 2 reversal faster than the shift from 100% to 50%. And rats learned the shift from 100% to 50% faster than the shift from 100% to 16.7% in reinforcement density in the present experiment. These findings were not consistent with the expectation from the reinforcement density view postulated by Zentall et al. (1991) and Zentall (1998).

The findings of the difference in the rate of reversal learning under partial reversal conditions in the present study could not be readily interpreted by either the rule-based account or the functional class account. From the rule-based account, rats of Group P-10 should learn their reversal faster than Group P-6, which in turn should learn faster than Group P-2, because Group P-10 entailed only 2 exceptions, whereas Group P-6 and Group P-2 required 6 and 10 exceptions. However these results were not observed in each experiment. On balance, from the functional class account, one might expect that Group P-10 should reverse faster than Group P-6, which in turn should reverse faster than Group P-2, because Group P-10 was numerically closer to the whole reversal than Group P-6 and Group P-2, respectively. But these results were not observed in present experiment. The data of Group P-10 might be the result of pitting contradictory contingencies, thus creating a very
difficult problem for rats to resolve. These findings indicated that the relationship of rule-based performances to functional stimulus classes was not simple.

Alternatively, if the rats solved the initial same-different problems based on figural symmetry, the rats might drop back to chance on all problems because this single invariant visual feature was no longer consistent with reinforcement. Thus, rats of Group P-2 would learn their reversal faster than Group P-6, which in turn should learn their reversal faster than Group P-10, which in turn should learn their reversal faster than Group Whole, because rats of Group P-2 had only 2, rather than 6, associations to relearn, and rats of Group P-6 had 6, rather than 10, and rats of Group P-10 had 10, rather than 12, associations to relearn. These results were partially observed in the present experiment. Thus, this alternative account could interpret the difference in the rate of reversal learning under the partial reversal conditions, whereas it could not interpret the whole reversal versus partial reversal advantage effect observed in the present experiment.

By contrast, the findings of the present experiment could be explained by Nakagawa's theory (1986, 1992, 1993b). The advantage effect of the whole reversal over the partial reversal found in the present experiment was consistent with the findings in two concurrent discriminations (Nakagawa, 1986, 1992, 1998, 1999a, 1999d, 2000b, 2001) and in matching- (or nonmatching)-to-sample discriminations (Delius et al., 1995; Nakagawa, 1999b, 2000a; Zentall et al., 1991). This finding suggested that the mechanism of stimulus classes formation between stimuli used in same-different discriminations was the same as that of stimulus class formation between the discriminative stimuli or sets of stimuli in both two concurrent discriminations and matching- (or nonmatching)-to-sample discriminations. According to Nakagawa's view (1986, 1992, 1993b), rats formed associations between the discriminative stimuli with the same response assignment during overtraining on two concurrent discriminations, and these associations mediated the transfer of appropriate responding when discriminations were reversed (Nakagawa, 1992). In the case of matching- (or nonmatching)-to-sample discriminations, rats associated a configuration of stimuli with lever pressing responses, and then formed associations between the configurations with the same response assignment. For example, in a matching-to-sample task, rats learned to associate one configuration of stimuli (i.e., AAB and BBA) with pressing the left lever followed by a reward, and the other configuration (i.e., BAA and ABB) with pressing the right lever followed by a reward (the two outer letters refer to the comparison stimuli, and the center letter refers to the sample stimulus). The rats then formed associations between the configurations with the same response assignment, and it was these configuration associations that mediate the transfer of appropriate responding to a subsequent shift problem (Nakagawa, 1993b). In same-different discriminations, we must allow rats to associate a configuration of stimuli with lever pressing responses, and then to form associations between the configurations with
the same response assignment. For example, rats learned to associate one configuration of stimuli (i.e., identical stimuli: AA, BB, CC, DD, EE, and FF) with pressing the right lever followed by a reward, and the other configuration (i.e., nonidentical stimuli: AB, BC, CD, DE, EF, and FA) with pressing the left lever followed by a reward (each letter referred to a stimulus item). The rats then formed associations between the configurations with the same response assignment, and it was these configuration associations that mediated the transfer of appropriate responding to a subsequent shift problem.

As a result of these configuration associations, the reversal of the one discrimination task (i.e., same task) in the whole condition should exert a synergistic influence upon the reversal of the other discrimination task (i.e., different task). Each reinforcement of the new positive lever in one discrimination should not only enhance the strength of the approach response to this lever but also augment the same response to the new positive lever in the other discrimination via the configuration association between the discriminative stimuli formed during the original same-different conditional discrimination training. Correspondingly, the consequences of nonreinforcement of the new negative lever should also transfer between two tasks of same and different tasks. By contrast, in the presence of configuration associations, continued training with the unreversed discrimination during the reversal stages would lead to interference with the development of an approach response to the new positive lever and of an avoidance response to the negative lever of the reversed discrimination. Consequently, the whole group should master their reversal faster than the partial groups. This proposal was supported by the finding of the present experiment.

The findings that, under partial reversal conditions, Group P-2 reversed faster than Group P-6, which in turn reversed faster than Group P-10 was in line with findings of Experiments 1, 2, and 3 in Nakagawa (2000a). Experiment 3 of Nakagawa (2000a) had reported that Group W, in which rats were given reversal training on all three tasks (i.e., from B+W-; H+V-; T+C- to B-W+; H-V+; T-C+ for example), reversed faster than Group P-1 (i.e., from B+W-; H+V-; T+C- to B+W-; H-V+; T+C- for example), in which rats were given reversal training on only one of the three tasks, which in turn reversed faster than Group P-2 (i.e., from B+W; H+V-; T+C- to B+W-; H-V+; T-C+ for example), in which rats were given reversal training on two of the three tasks, after overtraining, whereas Group P-1 reversed faster than Group P-2, which in turn reversed faster than Group W, after criterion training in three go/no-go concurrent discriminations. According to Nakagawa's view (1986, 1992, 1998, 1999a, 1999b, 1999c), rats formed stimulus classes between discriminative stimuli with the same response assignment after overtraining but not after criterion training in concurrent discriminations. Therefore, if the six associations in the original learning were independent of one another, one would have expected that Group P-1 would have reversed faster than Group P-2, which in turn would have
reversed faster than Group W because animals of Group P-1 had only two, rather than four, associations to relearn, and animals of Group P-2 had four, rather than six, associations to relearn. Thus, the difference in the rate of reversal learning between Groups P-1 and P-2 after overtraining in Experiment 3 of Nakagawa (2000a) made it clear that overtrained rats of Groups P-1 and P-2 have dissociated functional stimulus classes between discriminative stimuli established during overtraining to resolve their reversal in Phase 2. Taken together with the findings of Nakagawa (1999b, 2000c) that the same mechanism governed the formation of associations between stimuli in either concurrent discriminations, matching- (or nonmatching)-to-sample discriminations, or same-different discriminations in rats, the findings of Experiment 3 in Nakagawa (2000a) suggested that in resolving partial reversals, rats should firstly dissociate functional stimulus classes formed in Phase 1 training in same-different discriminations, and then reacquire new stimulus-stimulus associations. If rats of partial reversal groups had dissociated functional stimulus classes in resolving their partial reversals, 12 stimulus sets would be independent of one another in reversal learning. Thus, rats of Group P-2 would learn their reversal faster than Group P-6, which in turn should learn their reversal faster than Group P-10, because rats of Group P-2 had only 2, rather than 6, associations to relearn, and rats of Group P-6 had 6, rather than 10, associations to relearn. These results were observed in the present experiment. Thus, a partial reversal operation had a function to dissociate functional stimulus classes established in Phase 1 training so that, under partial reversal conditions, the number of stimulus-stimulus associations to relearn contribute to the rate of reversal learning.

Figures 3, 4, and 5 indicated that rats were learning about stimulus-stimulus relationship (i.e., stimulus configuration-stimulus configuration relationship) between stimuli on a basis of learning about individual stimuli and individual problems during Phase 1 same-different discrimination training. If rats were learning about individual stimuli and individual problems but not about stimulus configuration-stimulus configuration relationship, accuracy scores of rats in Group P-2 should maintain at 83% correct level in early sessions during reversal learning and their accuracy scores on the unreversed tasks should be above a high correct level (i.e., 83% correct level) and should not drop at chance level (i.e., 40 to 60% correct level) in reversal learning. Because when reversing only 2 of the 12 problems in Group P-2, the rats could still perform at 83% correct simply by maintaining their existing discrimination habit. Furthermore, accuracy scores on the unreversed tasks of rats in both Groups P-10 and P-6 should not drop at chance level in reversal learning. But these results were not observed in the present experiment.

The results of the present experiment were not readily explained by any account grounded in an increased distinctiveness of the same and different relation that were caused by the larger numbers of elements used in the displays and the concurrent use of large numbers of stimulus exemplars during training (Cook et al., 1995; Wasserman et al., 1995). The present experiments have involved the classification of just two visual items as same
or different. According to an account grounded in increased distinctiveness of the same and different relation, rats should not, for example, acquire same-different relations. But rats acquired same-different relations and transferred them to subsequent stimuli in the present experiments.

No studies had reported that pigeons and rats formed functional stimulus class formation between discriminative stimuli in same-different discriminations. The present study was the first study that systematically examined functional stimulus classes formation in same-different discriminations in rats using the whole-partial reversal procedure by conducting a parametric analysis of reinforcement density. The present study made it clear that rats formed functional stimulus classes between stimuli in same-different discriminations: This is the novel empirical contribution to the literature of stimulus classes formation in rats.

The findings of the present experiment offered strong evidence that rats formed functional stimulus classes between stimuli in same-different discriminations involving only two visual stimulus items.

References


