Numerousness Discrimination in Rats

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Abstract

Three experiments were conducted to test rats' ability to acquire conceptual two-choice visual numerousness discriminations. A touch-screen presented stimuli (white dots) and recorded responses. In Experiment 1, three rats were trained on a 3:4 discrimination with trial-unique dot displays (probes) presented on either 20% or 5% of trials. All subjects performed at chance on both training trials and probes. In Experiment 2, four rats were trained on a 3:6 discrimination with probes presented on all trials. All subjects performed at chance. In Experiment 3, four rats were trained on a 2:5 discrimination without probes. All subjects learned this discrimination. Probes were then presented on 25%, followed by 75% of trials. All subjects performed significantly above chance on the probes indicating acquisition of a conceptual 2:5 numerousness discrimination. These rats were then tested on additional discriminations. Above chance performance was obtained on the 2:4, 3:5, and 4:5 tasks indicating acquisition of conceptual numerousness discriminations on these tasks as well. Data collection is still underway on the 2:3 task.

Introduction

The study of numerical cognition in animals has been the focus of much research, debate, and controversy in the field of animal intelligence [10,11,13, 17,21,29,31]. Several different mechanisms have been proposed to account for the various levels of numerical competence observed. These mechanisms include subitizing [11,19], relative and absolute conceptual numerousness judgments [11,25,26,27,28,29], protocounting [11,18], a preverbal counting mechanism [13,14,15], and other varieties of non-verbal counting [2,3,11].

Animals do display remarkable abilities in tasks designed to test numerical competence. Primates exhibit the most sophisticated numerical cognition. Chimpanzees have been reported to be able to count [2,3], associate symbols with quantity [3,19], and compare and combine (i.e., sum) mental representations of quantity [1,3,20]. Rhesus monkeys have been reported to acquire an absolute numerousness concept of "threeness" [16] and to mentally represent 1-9 items along an ordinal scale [4]. A baboon and a squirrel monkey have been reported to represent and order items in a similar way [22]. Squirrel monkeys have been shown capable of both relative and absolute conceptual numerousness judgments [24, 27,28] and of summation based on the number of sides of polygons [24].

Non-primate species have also shown impressive numerical competence. Raccoons are capable of acquiring the absolute numerousness concept "threeness" [7], and crows and pigeons are capable of acquiring relative numerousness concepts such as "larger set" [33] and "many" vs "few" [12]. Pigeons have also been shown capable of associating symbols with numbers of items [32] and of mentally representing 1-7 items along an ordinal scale [12].

Research with rats has also indicated a high level of numerical competence. One early study [30] reported that rats could acquire the absolute numerousness concept of "two", and a more recent study [9] reported that rats acquired a relative numerousness concept. Other recent research has suggested much more sophisticated numerical cognition in rats. At least four published reports [5,6,8,23] have concluded that rats have the ability to count to some degree. The numerical stimuli used in these studies were sequences of sound events [5], numbers of reinforcing events [6], and ordinal positions of goal boxes [8,23].

The present study was conducted to further investigate numerical competence in rats. Visual stimuli and two-choice simultaneous numerousness discrimination tasks were used. Trial-unique displays of white dots, equated for brightness, were used to rule out the potential use of non-number visual cues such as pattern and cumulative area/brightness. In Experiment 1, a 3:4 discrimination was tested. In Experiment 2, a 3:6 discrimination was tested. In Experiment 3, a 2:5 discrimination was tested after which the rats were tested on additional discriminations (2:4, 3:5, 2:3, and 4:5).

Experiment 1

Method

Subjects. Three adult male rats of the Dark Agouti (DA/OlaHsd) strain were used. Two had been used previously in a two-choice visual pattern discrimination study, and one had been used in a three-choice visual oddity study. All were housed singly in standard rodent cages and maintained at 90% of their adult free-feeding body weight. Water was provided *ad libitum*. A 12:12 light dark cycle was maintained throughout the study. All animals were treated ethically under the guidelines of the American Psychological Association and approval for their use was obtained from the Columbus State University Animal Care and Use Committee.

Apparatus. A computer-controlled touch-screen system was used to present stimuli and record responses (Figure 1). A plastic enclosure (70 cm x 30 cm x 30 cm) open at one end was placed flush against a 50 cm diagonal capacitive touch-screen (Mitsubishi). A food pellet dispenser could be placed at one of three locations along the side of the enclosure, and at one location at the rear of the enclosure. Software controlling the experimental sessions was developed using Turbo Pascal for DOS version 7.0 (Borland).

Stimuli. Visual stimuli were displays of 3 and 4 white dots presented against a black background on the touch-screen. Each display was presented within a 9 cm x 9 cm area on the left and right sides of the screen. Training stimuli were composed of dots of various sizes arranged in specific patterns. Test stimuli were composed of dots arranged in random, trial-unique patterns. With both the training and test stimuli, overall cumulative area/brightness of the dots in the two displays on each trial were equated. The sizes of the dots insured that the total number of pixels in both the 3-dot and 4-dot displays on each trial were within 95% of each other. See Figure 2 for the training stimuli and an example of the test stimuli used in Experiment 1.

Procedure. The rats were first shaped to touch a single white shape (diamond) on the touch-screen to obtain reinforcers (45 mg food pellets). The rats were gradually required to move to the rear of the enclosure to obtain their food pellets. In the final stage of shaping, the rat initiated each subsequent trial when he retrieved his food pellet from the receptacle A "nose-poke" into the receptacle broke an infrared beam which signaled the computer to present the next trial. In this way, each rat determined his own rate of trial presentations and each rat was always positioned at the center rear of the enclosure at the beginning of each trial. Below is the sequence of events on each trial:

nose-poke → present stimulus → touch stimulus → food pellet → nose poke

After shaping, the rats were administered a 3:4 numerousness discrimination task. Three-dot and four-dot displays were presented on the left and right sides of the screen on each trial. Left and right placement was determined pseudorandomly using the Fellows series. For two of the rats, 80% of the trials in each session were training trials and 20% were randomly inserted test trials (probes). For the third rat, 95% of the trials were training trials and 5% were randomly inserted probes. Training and testing continued for several hundred trials for each rat (see Table 1).

Results

None of the three rats showed above-chance performance on the 3:4 numerousness discrimination task with either the training or the test stimuli (see Table 1).

Table 1. Percent Correct on the Training and Test Trials of Experiment 1

	3:4 Task	
Rat	Training trials	Test trials
B4B	49% (1620 trials)	47% (70 trials)
R2B	50% (1840 trials)	50% (473 trials)
R3B	50% (1280 trials)	51% (323 trials)

Experiment 2

Method

Subjects. Four adult male rats of the Dark Agouti (DA/OlaHsd) strain were used. All were experimentally naïve.

Apparatus. Same as in Experiment 1.

Stimuli. Same as in Experiment 1 except that 3-dot and 6-dot displays were used, test stimuli were presented on each trial, and overall cumulative area/brightness of the dots in the two displays was not equal (i.e., 6-dot displays were brighter on average than 3-dot displays). See Figure 3 for examples of the test stimuli used in Experiment 2.

Procedure. Same as in Experiment 1 except that a 3:6 numerousness discrimination task was administered and test stimuli were presented on every trial (i.e., no training stimuli were used). The accuracy criterion for learning the 3:6 task was 61% correct in a block of 100 test trials (p <. 05, Binomial test, two-tailed). Testing continued for an extended period for each rat (~2000-3100 trials).

Results

Figure 4 shows the accuracy data for each rat across blocks of 100 test trials on the 3:6 numerousness discrimination task. Three of the four rats reached the accuracy criterion of 61% correct in at least one block (see Table 2).

Table 2. Proportion of Trial Blocks in which the Accuracy Criterion (61%) was Reached by Each Rat in Experiment 2.

Rat	Proportion
G1A	0 blocks / 20 blocks
G2A	4/31
G3A	2/25
G4A	1/27

Experiment 3

Method

Subjects. Four adult male rats of the Dark Agouti (DA/OlaHsd) strain were used. All four had been used previously in a study of the effects of early-life environmental enrichment on learning. The rats had been raised in an enriched environment (toys, running wheel, ladders, etc.) early in life and then transferred to standard rodent cages in adulthood. A two-choice spatial reversal task had been used to assess learning in the previous study.

Apparatus. Same as in Experiments 1 and 2.

Stimuli. Same as in Experiments 1 and 2 except that 6-dot displays were not used and 2-dot and 5-dot displays were used in addition to 3-dot and 4-dot displays. See Figure 5 for the training stimuli and examples of the test stimuli used in Experiment 3.

Procedure. Same as in Experiments 1 and 2 except that multiple discrimination tasks were administered to each rat. The first task administered to each rat was a 2:5 numerousness discrimination task in which all of the trials were training trials. The accuracy criterion for learning this training task was 80% correct in two consecutive blocks of 20 trials (p <. 001, Binomial test, two-tailed).

When a rat reached criterion, 2:5 test trials (probes) were inserted on 25% of the trials. After a total of 300 probes had been administered, the proportion of test trials was increased to 75%. Testing continued in this way until 1500 test trials had been administered, or until a subject achieved 80% correct in a block of 100 test trials. Next, a single block of 100+ test trials was administered in which the dots in both the 2-dot and 5-dot displays were the same size. This was done to test for the possibility that dot size may have been a potential non-number cue for correct responding.

After a rat finished the 2:5 task it was moved to either a 2:4 or 3:5 numerousness discrimination task. The two rats that had 5 dots as their positive stimulus in the 2:5 task were moved to the 3:5 training task with 5 dots still positive. The two rats that had 2 dots as their positive stimulus in the 2:5 task were moved to the 2:4 training task with 2 dots still positive. When a rat reached the learning criterion on this training task, test trials were inserted on 75% of the trials and testing continued until 1500 test trials had been administered, or until a subject obtained 80% correct in a block of 100 test trials. Then, a single block of 100+ test trials was administered in which all the dots were the same size.

After a rat completed the 2:4 or 3:5 numerousness discrimination task, it was then moved to either a 2:3 or 4:5 discrimination task and training/ testing continued as described above.

Results

All four rats reached criterion on the 2:5 training task. The four rats trained on the 2:4 and 3:5 training tasks also reached criterion. One of the two rats trained on the 4:5 training task has reached criterion. Training is still in progress for three of the rats (see Table 3).

Table 3. Number of Trials-to-Criterion for Each Rat on the Training Tasks of Experiment 3

			Task		
Rat	2:3	2:4	2:5	3:5	4:5
G1C	----	----	1120	120	580
G2C	(in progress)	400	1480	----	----
G3C	----	----	1320	40	(in progress)
G4C	(in progress)	240	2140	----	----

Figure 6 shows the accuracy data for each rat across blocks of 100 test trials on the numerousness discrimination tasks. Each of the rats reached the accuracy criterion of 61% correct in at least 50% of the trial blocks (see Table 4).

Table 4. Proportion of Trial Blocks in which the Accuracy Criterion (61%) was Reached by Each Rat in the Test Trials of Experiment 3.

			Task		
Rat	2:3	2:4	2:5	3:5	4:5
G1C	----	----	7/7	15/16	8/16
G2C	(in progress)	15/16	12/16	----	----
G3C	----	----	16/16	8/16	(in progress)
G4C	(in progress)	15/16	14/16	----	----

Discussion

In a series of three experiments, eleven rats were trained and tested for the ability to acquire conceptual two-choice visual numerousness discriminations. In Experiment 1, none of the four rats learned the 3:4 training task and none showed above-chance performance on the trial-unique test trials. In Experiment 2, three of the four rats showed some evidence of above-chance performance on the 3:6 test trials, but this performance was inconsistent (see below). In Experiment 3, all four rats showed consistent above-chance performance on the 2:5 test trials. Two rats also showed above-chance performance with the 2:4 test trials, two with the 3:5 test trials, and one with the 4:5 test trials.

The reasons for the poor performances of the rats in Experiments 1 and 2 is unclear in light of the performance of the rats in Experiment 3. One reason the rats in Experiment 1 may not have learned the task is because training and test trials were intermixed, occurring within the same session. For two of the rats (R2B and R3B), test trials occurred on 25% of the trials administered. This relatively high proportion of test trials with trial-unique dot displays may have hindered learning of the training stimuli. After the poor performances of these two rats were analyzed, a third rat (B4B) was added to the study and test trials occurred on only 5% of the trials administered in each session for this rat. Still, only chance performance was demonstrated by this rat suggesting that the high proportion of test trials may not have been the cause of the poor performances of the other two rats.

The rationale for Experiment 2 was that perhaps extended training with only trial-unique test stimuli might better stimulate learning of a numerousness discrimination. Since only trial-unique stimuli were used throughout testing, the influence of the repeated presentation of specific patterns of dots would be less. This might "release" the rats from attempting to learn specific reinforced patterns and encourage a more flexible (i.e., conceptual) learning approach. The 3:6 task was chosen in an effort to use a numerousness discrimination task that was presumed to be less difficult than the 3:4 task used in Experiment 1. Three of the rats showed above-chance performance on a subset of the trial blocks (Table 2) but this performance was inconsistent. For example, G3A's above-chance blocks occurred early in testing but not later. G4A's two above-chance blocks occurred in the middle of testing but not later. Only G2A showed a trend toward above-chance performance toward the end of testing and this rat also had the largest proportion of above-chance blocks (4/31). Still, this small proportion suggests that a conservative conclusion is warranted, and that none of these four rats acquired a conceptual 3:6 visual numerousness discrimination.

The rationale for Experiment 3 was that perhaps exclusive training with numerousness displays composed of specific dot patterns might facilitate learning of two-choice dot discriminations in general, and this learning might transfer to trial-unique dot displays later. A rigorous training criterion was used (80% correct in two successive 20-trial blocks) to insure that the training displays were fully learned prior to the introduction of test stimuli. The 2:5 task was chosen in an effort to use a task that was presumed to be less difficult than the 3:6 task used in Experiment 2, and also less difficult than the 3:4 task used in Experiment 1.

The results from Experiment 3 were quite different from the results of Experiments 1 and 2. All four rats showed consistent above-chance performance on the 2:5 test trials. When transferred to new discrimination tasks, the rats also showed consistent above-chance performance with the 2:4 test trials, the 3:5 test trials, and the 4:5 test trials. When tested with dots of constant size in the last trial block of each task, all rats except one (G2C; 2:4 task) continued to show above-chance performance indicating that dot size had not been used as a cue for correct responding in the previous blocks. Taken together these results indicate that rats are capable of acquiring conceptual visual numerousness discriminations in the range of 2-5 items.

One possibility for the positive results of Experiment 3 might be the fact that these subjects had been used in a previous study where that had been raised in an "enriched" environment containing toys, a running wheel, and ladders. An abundance of previous research has demonstrated that early-life environmental enrichment can have positive effects on learning ability in adulthood [34]. It is possible that the rats in Experiment 3 benefited from this enrichment. A future study should be conducted in which a comparison group raised in a standard (impoverished) environment is included.

The specific cognitive mechanism allowing the rats of Experiment 3 to acquire conceptual numerousness discriminations is not clear. They may have been using the preverbal counting mechanism described by C.R. Gallistel [13,14,15] or they may have been using relative and/or absolute numerousness judgments as described by R.K. Thomas [25,26,27,28,29]. Additional research is needed to determine the mechanisms at work. However, the present study does provide convincing evidence that rats can acquire visual numerousness discriminations and apply them to trial-unique stimuli in which non-number cues are controlled.

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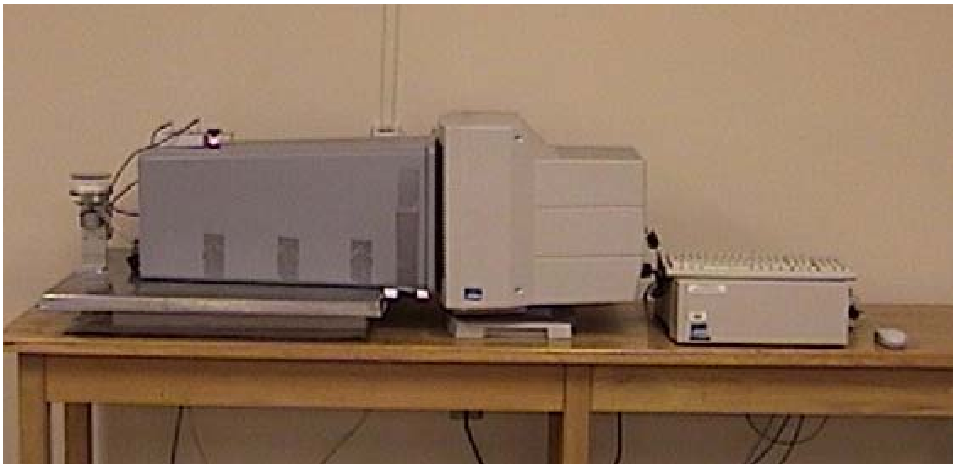

Figure 1. Apparatus

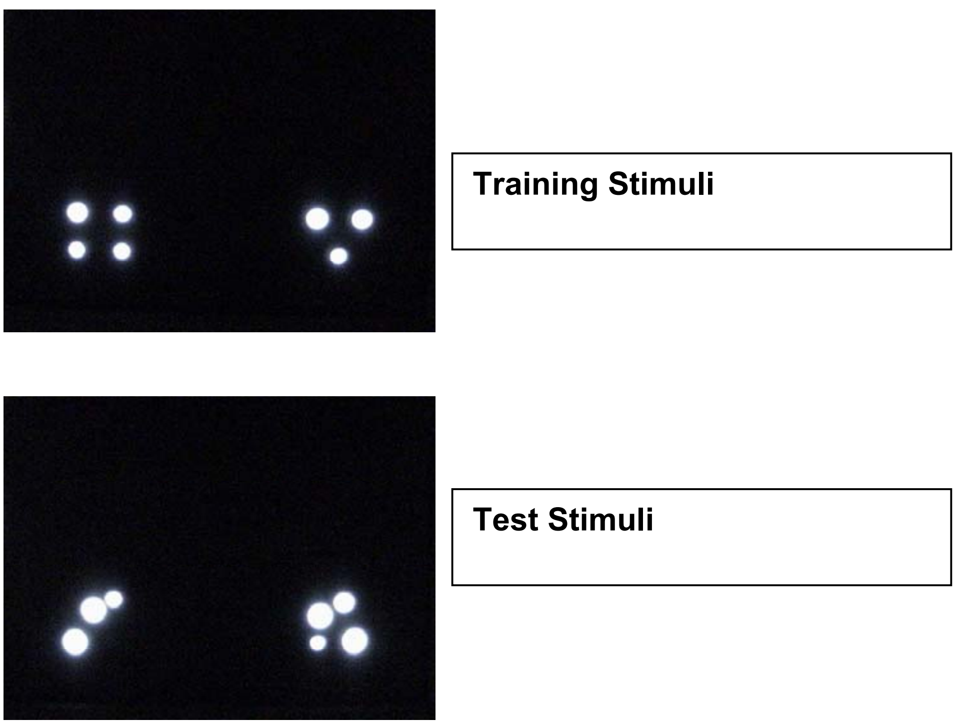

Figure 2. Training stimuli and an example of the test stimuli used in Experiment 1.

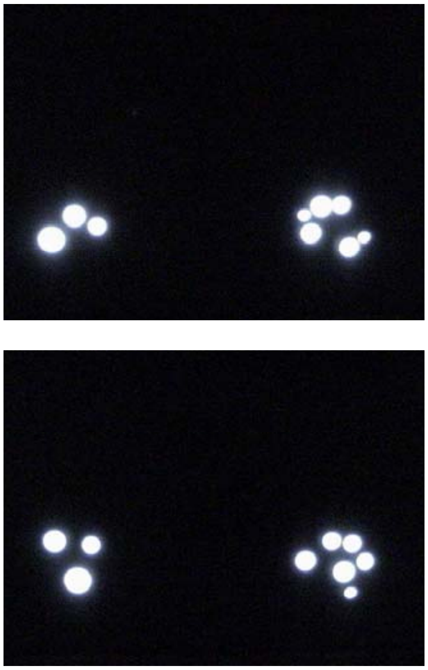

Figure 3. Examples of the test stimuli used in Experiment 2.

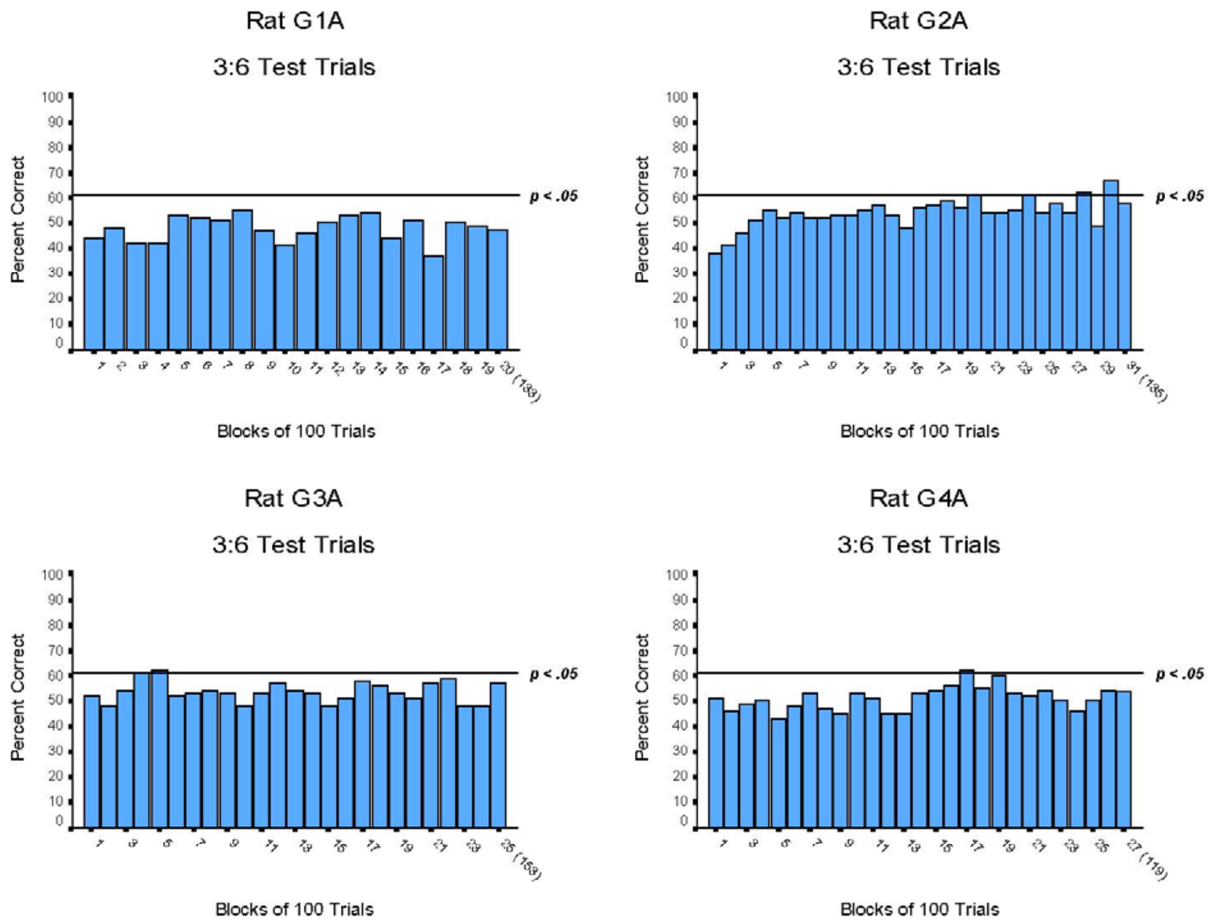

Figure 4. Percent correct for each rat across blocks of 100 test trials in Experiment 2.

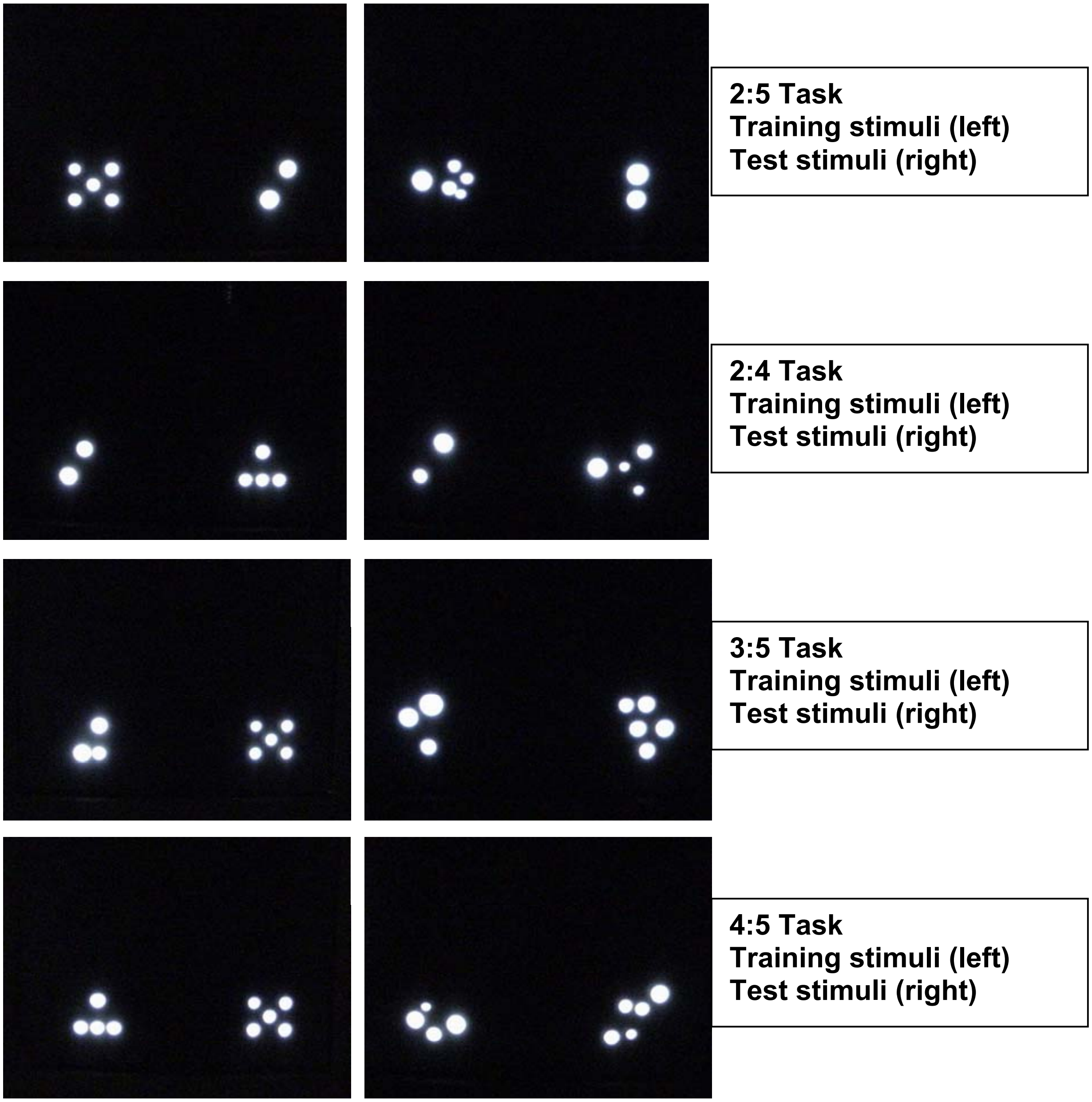

Figure 5. Training stimuli and examples of the test stimuli used in Experiment 3.

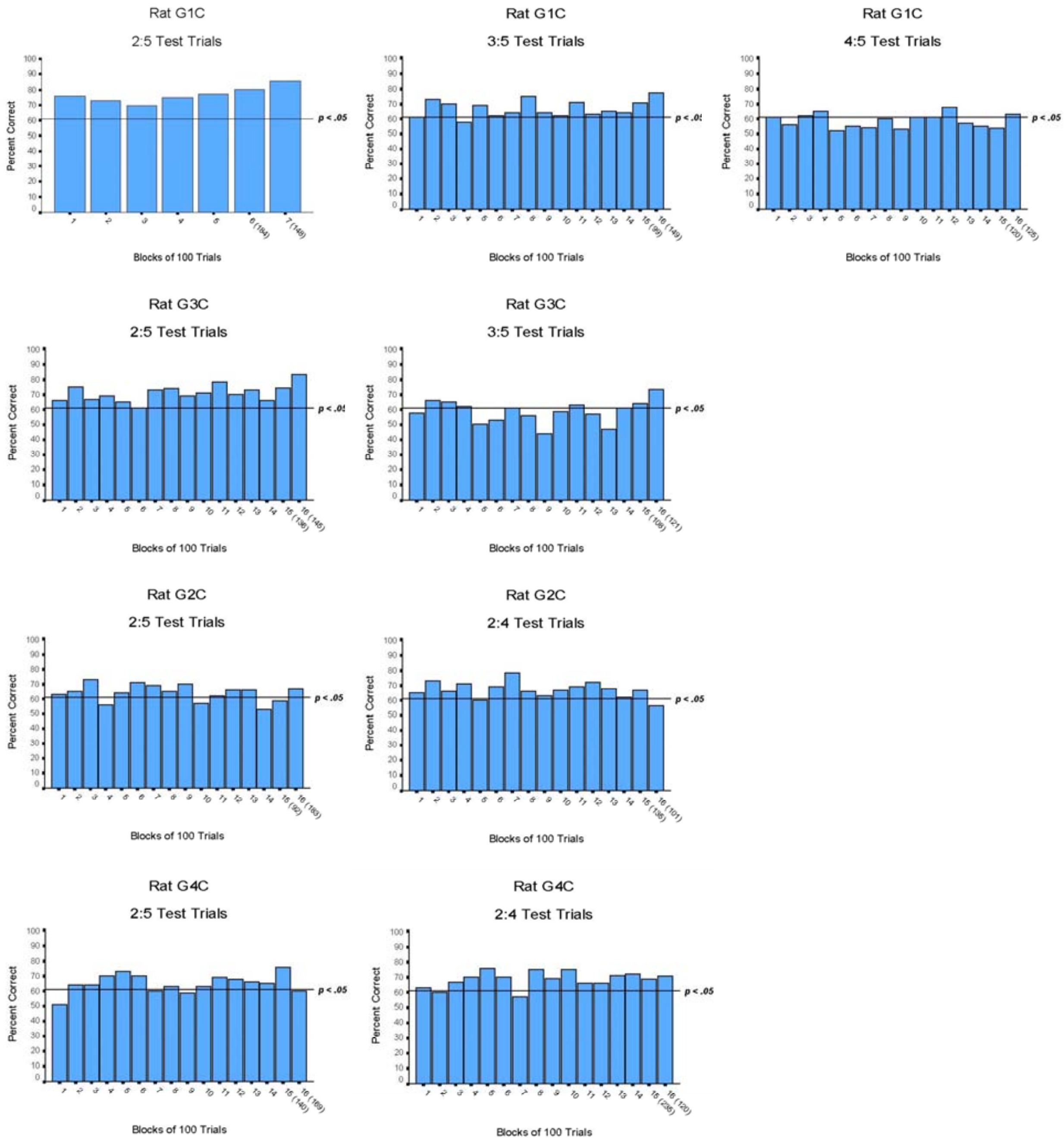

Figure 6. Percent correct for each rat across blocks of 100 test trials in Experiment 3. In the last block of trials on each task, the dots in the displays were all the same size.