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ORIGINAL PAPER

Effects of training condition on the contribution of specific items to relational processing in baboons (*Papio papio*)

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Abstract Relational processing involves learning about the relationship between or among stimuli, transcending the individual stimuli, so that abstract knowledge generalizable to novel situations is acquired. Relational processing has been studied in animals as well as in humans, but little attention has been paid to the contribution of specific items to relational thinking or to the factors that may affect that contribution. This study assessed the intertwined effects of item and relational processing in nonhuman primates. Using a procedure that entailed both expanding and contracting sets of pictorial items, we trained 13 baboons on a two-alternative forced-choice task, in which they had to distinguish horizontal from vertical relational patterns. In Experiment 1, monkeys engaged in item-based processing with a small training set size, and they progressively engaged in relation-based processing as training set size was increased. However, in Experiment 2, overtraining with a small stimulus set promoted the processing of item-based information. These findings underscore similarities in how humans and nonhuman primates process higher-order stimulus relations.

Keywords Baboon · Comparative psychology · Abstract concept learning · Item processing · Relational processing

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Introduction

Relational processing requires learning about the relations between or among two or more stimuli (e.g., sameness, differentness, oddity, less than, and greater than); the specific perceptual properties of the stimuli must be transcended, and knowledge of universal applicability must be extracted (Morgan 1896). Relational processing is vital to higher-order cognition in humans and is central to a variety of adaptive cognitive processes, including analogical reasoning (Vosniadou and Ortony 1989), categorization (Ramscar and Pain 1996), and inductive inference (Holland et al. 1989).

Some authors (e.g., Penn et al. 2008) have proposed that there is a sharp distinction between perceptually based behavior, based on the perceptual features of the stimuli, and conceptually based behavior, based on the abstract properties of the stimuli. In this article, we focus on how these two different kinds of information *jointly* participate in relational learning, and how the nature and quantity of experience of the learner interact with the processing of perceptual properties, such as the individual items presented, and their abstract properties, such as the relations between or among the presented items.

During human and animal development, processing the perceptual characteristics of stimuli seems to precede and support the emergence of abstract concepts and relational representations (Herrnstein 1990; Murphy and Smith 1982; Tomikawa and Dodd 1980; Zentall et al. 2008). Young children initially pay more attention to perceptual features than to the relational structures that bind stimuli together (Christie and Gentner 2007), but a relational shift later occurs and children progressively move their attention from perceptual attributes to higher-level properties, such as relational structures. The ability to process relational structures is directly linked to the knowledge that children acquire about relations; the more experience children have with a particular relational concept, the better their ability to transfer that concept to new domains (Goswami and Brown 1990a, b). This developmental progression suggests that the variety of stimuli exemplifying a relationship to which a learner is exposed will play an important part in his/her ability to detect higher-level structures.

Relational learning in animals is often studied with same/different (Blaisdell and Cook 2005; Katz et al. 2002; Oden et al. 1990; Wasserman and Young 2010; Wright et al. 2003) and matching-to-sample tasks (Bodily et al. 2008; Truppa et al. 2010; Wasserman and Castro 2012). Use of these procedures has demonstrated that pigeons (Cook and Wasserman 2012; Katz and Wright 2006), parrots (Pepperberg 1987), rats (Nakagawa 1993; Wasserman et al. 2012), dogs (Pietrzykowska and Soetysik 1975), and nonhuman primates (Katz et al. 2002) can form abstract concepts, suggesting that this ability is widespread among animals. Even when presented with more challenging cognitive tasks, which require the animals to learn not only first-order relationships (as in a same-different task) but also second-order relationships (the relationship between relations, as in a relational matching-to-sample task), some animals have shown reliable success (e.g., Fagot and Parron 2010; Fagot and Thompson 2011; Fagot et al. 2001; Flemming et al. 2011; Vonk 2003).

Abstract concept learning in animals has been found to be boosted when they are trained with large sets of training items compared with small sets of training items (pigeons: Castro et al. 2010; Katz and Wright 2006; rhesus monkeys: Katz et al. 2002; capuchin monkeys: Truppa et al. 2010). In general, as the number of items in the training set progressively increases, transfer performance steadily rises, suggesting that the number of instantiations of a relational concept directly influences an animal's ability to appreciate it. A plausible reason for this set size effect is that the more items are in the training set, the more difficult it becomes to learn specific responses to specific stimuli. Because stimulus *identity* becomes difficult to use as a discriminative feature when the number of items is large, the animals must learn about the *relation* between or among the stimuli.

Studies conducted in humans suggest that the processing of perceptual features and stimulus relations may be *interdependent*. For instance, Rein and Markman (2010) trained participants to identify visual relational patterns (either horizontal or vertical groupings of items) instantiated by arrays of different individual items; they found that, when novel items were presented forming the horizontal and vertical relational patterns, participants' responses were slowed and their error rates were increased. That is, participants found it more difficult to judge the abstract relations with novel items, suggesting that, even when abstract relations had been taught (participants were given explicit instructions to learn the relation among the items), the influence of the particular items involved in those relations persisted.

Similar conclusions were made by Kroger et al. (2004), who asked their participants to judge whether the relations among patterns of four colored squares were the same either based on the specific squares or based on the relationship among the squares. When the participants had to judge similarity at the relational level (among the patterns rather than among the single squares), their response times were influenced by the similarity of the specific squares, suggesting that processing of the stimuli at the item level had an influence on processing the stimuli at a still higher relational level. In a similar vein, Gentner and Markman (1997) found that participants more readily discerned relational similarity when the properties of the stimuli instantiating the relations were similar to one another than when they were different from one another. Altogether, the findings from these studies strongly suggest that, at least for humans, there may be no sharp distinction between relational processing and the processing of perceptual features, including the specific stimulus items themselves.

The contribution of item processing to relational representation seems to depend on the individual's prior experience with the specific items illustrating the relation, as well as on the individual's prior experience with the relation itself (Markman and Gentner 1993; Richland et al. 2006). Markman and Gentner (1993) presented college students with an analogical reasoning task involving pairs of scenes depicting one particular relation (e.g., Scene 1: a bird chasing a worm; Scene 2: a cat chasing a bird). The experimenter pointed to one item in Scene 1 (e.g., the bird) and asked the participant to select the corresponding item in Scene 2 (e.g., the cat). Relational similarity seemed to be more salient when the participants had previously seen several pairs of stimuli before they were asked to solve the task. Also using analogy scenes, Richland et al. (2006) found that young children were highly sensitive to distraction by the specific stimuli used in the scenes, but this sensitivity tended to decline with age. Overall, the likelihood of a child attending to the relational structure of a task and disregarding the irrelevant features of the individual items appeared to depend on the richness of the child's experience with the relation.

Studies of relational learning in nonhuman animals have been primarily interested in documenting their higher-order cognitive capabilities (Fagot and Maugard 2013; Fagot and Thompson 2011; Gillan et al. 1981), with rather less interest having been paid to animals' possible processing of individual items during relational learning (Maugard et al. 2013). Thus, the first aim of the current study was to assess the possibly intertwined effects of item and relational processing in nonhuman primates, specifically baboons. Because baboons are capable of solving same–different (Wasserman et al. 2001) and relational matching-to-sample problems (Fagot et al. 2001; Fagot and Thompson 2011; Fagot and Maugard 2013; Maugard et al. 2013), this species was an interesting model for our study. The second aim was to investigate the effect of experience on the modes of information processing that animals deploy to master relational learning tasks.

Our experimental designs were largely inspired by Rein and Markman's recent (2010) study on the interplay between item and relational processing in human cognition. Critical to the tasks that we gave our baboons was the fact that task mastery was possible by processing either the items in the stimulus arrays or the relations that built upon those items (or both). With such redundant relevant cues at their disposal, the baboons could attend to either in order to solve the problem (also see Gibson and Wasserman 2003, 2004 for similar work with pigeons). To which kind of information would they attend? Could they process the item information or the relation information (or both) at the same time? What factors might incline them to attend to one property or the other? These were the questions to which we sought answers.

Experiment 1

In Experiment 1, we trained guinea baboons (*Papio papio*) on a two-alternative forced-choice task, in which they had to discriminate horizontal from vertical relational patterns. In Phase 1, each spatial relation was exclusively expressed by a unique object (e.g., heart shape = horizontal; L shape = vertical, see Fig. 1a); the number of objects expressing each spatial relation was increased to 6 in Phase 2 and to 60 in Phase 3 (see details below). After each phase of training, we tested the baboons under the four different transfer conditions illustrated in Fig. 1.

Each transfer condition was designed to disrupt different kinds of perceptual information. First, Novel configuration transfer trials contained the same objects in the same relational patterns as the training trials, but the spatial location of the vertical or horizontal patterns within the overall stimulus differed from the training trials (see Fig. 1b). Second, Switched objects transfer trials contained the same objects as the training trials, but their function was reversed; the heart shape was now used to draw the vertical pattern, and the L shape was now used to draw the horizontal pattern (see Fig. 1c). Third, Novel objects transfer trials used Novel objects to draw the vertical or horizontal patterns, but retained the training background objects (see Fig. 1d), so that novel horizontal and vertical patterns were presented in a familiar context. Note that the items creating the background were the same for vertical and horizontal trials, so they could not be used to correctly

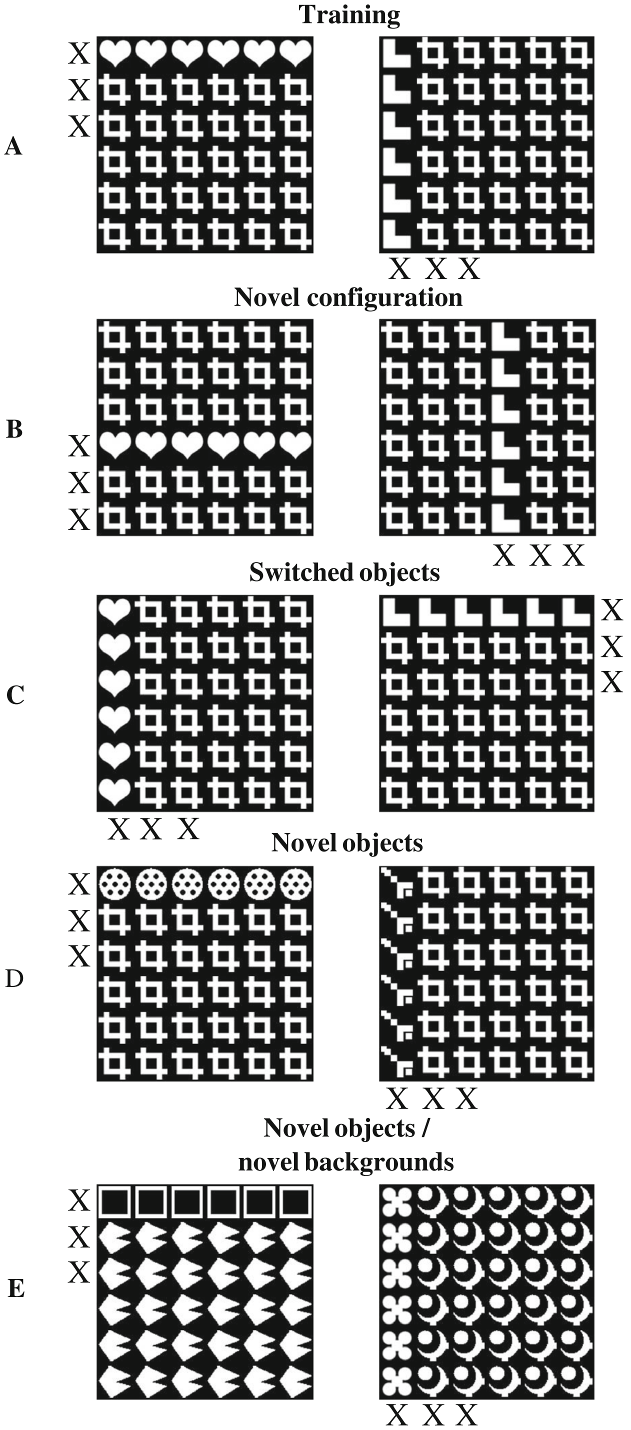

Fig. 1 Illustration of the horizontal and vertical displays used in training and transfer trials. In both the training and the transfer trials, horizontal (*left*) and vertical (*right*) patterns could be, respectively, displayed along the three different lines or columns denoted by the "Xs" next to each array. These test conditions were largely inspired by Rein and Markman (2010)

solve the task; still, some level of familiarity with the elements of the arrays may help the baboons' transfer performance. Fourth, Novel objects/Novel backgrounds transfer trials used Novel objects for drawing both the backgrounds and the patterns (see Fig. 1e), so that both the vertical and horizontal patterns and the backgrounds in which they were presented were unfamiliar.

This general testing procedure was given in three phases, as we progressively increased the size of the training stimulus sets (see below). By comparing the baboons' patterns of responding across the different transfer conditions and test phases, we hoped to see to what extent individual item processing contributed to relational processing. If accuracy to all testing trials is high, then the animals will have shown clear relational processing of the information in the arrays. On the other hand, if the animals merely learned item-specific responses, then their performance will be at chance with Novel objects and Novel objects/Novel backgrounds trials, and it will be below chance with Switched objects trials (because the training objects will now form the opposite geometrical pattern); item-specific learning could result in high accuracy to Novel configuration trials if the animals disregard the specific location where the item is presented, or it could result in low accuracy if location is processed along with the specific identity of the item. In addition, these response patterns could change depending on the number of exemplars presented during training. If the size of the item pool, and therefore the number of exemplars used to express each of the relations, matters, then we might see a transition from item-specific to relational learning from Phase 1 to Phase 3.

Method

Subjects

The subjects were 13 Guinea baboons (*P. papio*; age range 2.4–8.4 years), which had from 2 to 5 years of experience with computerized tasks (Bonté et al. 2011; Goujon and Fagot 2013; Maugard et al. 2013). A subset of six baboons had already been tested on relational matching-to-sample tasks involving the relations of identity and nonidentity, but none of the subjects had previously been tested in tasks involving horizontal and vertical relations. The baboons lived in a social group of 30 individuals within a 700 m^2 enclosure and had free access from their enclosure to the experimental area. Each animal had a microchip implanted in each forearm for automatic identification inside the test chambers. The baboons were never food or water deprived for the purpose of this study, but they only received their entire daily food ration at 5:00 p.m.

Apparatus

This research used the automated learning device for monkeys (ALDM, see Fagot and Bonte 2010; Fagot and Paleressompoulle 2009), allowing the baboons to freely exit their social group to enter into one of the ten testing booths (70 cm × 70 cm × 80 cm) in order to work on the task. Each testing booth was accessible through an open back entrance fitted in its innermost front side with a view port (7 cm × 7 cm) and two hand ports (8 cm × 5 cm each). Through the view port, the monkeys could readily see a 19-inch LCD touch monitor installed at eye level 25 cm from the port. Introducing one hand through one of the hand ports allowed the baboon to interact with the touch screen. Two antennas fixed around each hand port automatically read the microchip in the forearm of the baboon when the animal introduced its hand through a hand port. Numeric identification signals from the arm tags served to trigger the computer-controlled presentation of the stimulus and to assign behavioral measures (stimulus choices and response times) to each subject. Correct responses were rewarded by a few grains of dry wheat delivered inside the test booth by a dispenser.

The experiment was controlled by a customized test program developed by JF with E-Prime (version 1.2, Psychology Software Tools, Pittsburgh). Using this program, the appropriate stimulus presentation for a given subject could be administered, irrespective of the order in which the baboons spontaneously entered the test booth and the specific test booth that the animal decided to use.

Stimuli

The individual stimuli were white geometrical shapes (40 × 40 pixels, 1.7 × 1.7 cm, corresponding to 3.9° of visual angle). The total size of the set of individual stimuli increased from Phase 1 to Phase 2 to Phase 3, as described below. Two additional stimuli were used to draw the response buttons: an orange rectangle and a blue oval drawn in a 120 × 120 pixel area (4.4 × 4.4 cm, 10.1° of visual angle). All stimuli were displayed at a resolution of 1,024 × 768 pixels.

General procedure

The trials started when the baboon introduced one hand through a hand port for self-identification. This action triggered the presentation of the trial assigned to that subject. A trial began with the presentation of a 6 × 6 grid of stimuli (465 × 465 pixels, 17.2 × 17.2 cm, subtending 39.4° of visual angle) on a black background. Forty-five pixels separated two adjacent stimuli within the grid in the center of the screen. On horizontal trials, one object (e.g., heart shape, see Fig. 1a) was repeated six times in order to form a horizontal line, so that the relation among the six replications of the item was horizontal; the rest of the grid was filled with a neutral background object (e.g., a square with extended sides, see Fig. 1a). On vertical trials, another object (e.g., an L shape, see Fig. 1a) was repeated six times in order to form a vertical line, so that the relation among the six replications of the item was vertical; the rest of the grid was filled with the same neutral background object as for the horizontal pattern (e.g., a square with extended sides, see Fig. 1a).

Following one touch anywhere in the array, two response buttons appeared on the screen: a blue oval shape on the bottom part of the left hemi-screen and an orange rectangle on the bottom part of the right hemi-screen. The baboons had to touch the orange rectangle when the stimulus array entailed a vertical pattern and to touch the blue oval when the stimulus array entailed a horizontal pattern. Touching the correct button cleared the screen and delivered a food reward. Touching the incorrect button also cleared the screen, but triggered a 3-s time-out indicated by a green screen. Horizontal and vertical trials were randomly presented, with the constraint that these two kinds of trials were evenly presented within a block of trials (see below). An intertrial interval of 3 s separated two successive trials, but this delay could be longer because the baboons initiated the trials by themselves. A maximum of 5 s was allowed for the baboons to respond on each trial. The trial was aborted when the baboon did not respond within this time frame. The accuracy of the response (i.e., correct or incorrect) served as the main dependent variable.

Experiment 1 consisted of three successive phases (described in detail below), with each phase consisting of training followed by transfer trials. In each training phase, the items used to draw the stimulus arrays were selected from three distinct stimulus pools: one for drawing the horizontal line patterns in horizontal trials (Pool H), one for drawing the vertical line patterns in vertical trials (Pool V), and a third one for drawing the backgrounds (Pool B).

For each phase, the training sessions were continually repeated until the baboons reached an accuracy level of 80 % correct or better in two consecutive sessions. Then, transfer testing began. Testing sessions contained both Baseline trials and Probe trials. The Baseline trials were identical to the training trials, using the same objects and the same reinforcement contingency for each correct or incorrect response. Each testing session contained 6 Probe trials per transfer condition (i.e., Novel configuration, Switched objects, Novel objects, Novel objects/Novel backgrounds). Depending on the transfer condition, we used random objects from the three training pools (i.e., Pool B, Pool H, and Pool V) or from a pool of Novel objects for the Novel objects and the Novel objects/Novel backgrounds conditions. Choice responses on probe trials were randomly reinforced at a likelihood of 80 %.

Training and testing in Phase 1

Training sessions consisted of 96 randomized trials (48 H-trials randomly intermixed with 48 V-trials). The three training pools used for drawing the sample displays contained 1 item each. The baboons needed a mean of 30 sessions (2,880 trials, range 480–5,376 trials) to reach a criterion of two consecutive sessions at 80 % correct. Transfer in Phase 1 involved five consecutive testing sessions. Each testing session contained 174 trials (150 Baseline trials and 24 Probe trials). For the Novel objects Probe trials and the Novel objects/Novel backgrounds Probe trials, a total of 18 stimuli that had never been shown before were used in each session.

Training and testing in Phase 2

Training sessions consisted of 216 randomized trials (108 H-trials randomly intermixed with 108 V-trials). The three training pools used for drawing the sample displays each contained 6 new items. The baboons needed a mean of 16 sessions (3,456 trials, range 1,080–7,992 trials) to reach a criterion of two consecutive sessions at 80 % correct. Transfer in Phase 2 involved 6 consecutive testing sessions. Each testing session contained 240 trials (216 Baseline trials and 24 Probe trials). For the Novel objects Probe trials and the Novel objects/Novel backgrounds Probe trials, a total of 18 stimuli that had never been shown before were used in each session.

Training and testing in Phase 3

Training sessions consisted of 216 randomized trials (108 H-trials randomly intermixed with 108 V-trials). The three training pools used for drawing the sample displays each contained 60 items. The baboons needed a mean of 40 sessions (8,640 trials, range 3,888–13,824 trials) to reach a criterion of two consecutive sessions at 80 % correct. Transfer in Phase 3 involved 6 consecutive testing sessions. Each testing session contained 240 trials (216 Baseline trials and 24 Probe trials). For the Novel objects Probe trials and the Novel objects/Novel backgrounds Probe trials, a total of 18 stimuli that had never been shown before were used in each session.

Results

Arcsine transformations were applied to the baboons' accuracy data to correct for deviations from normality.

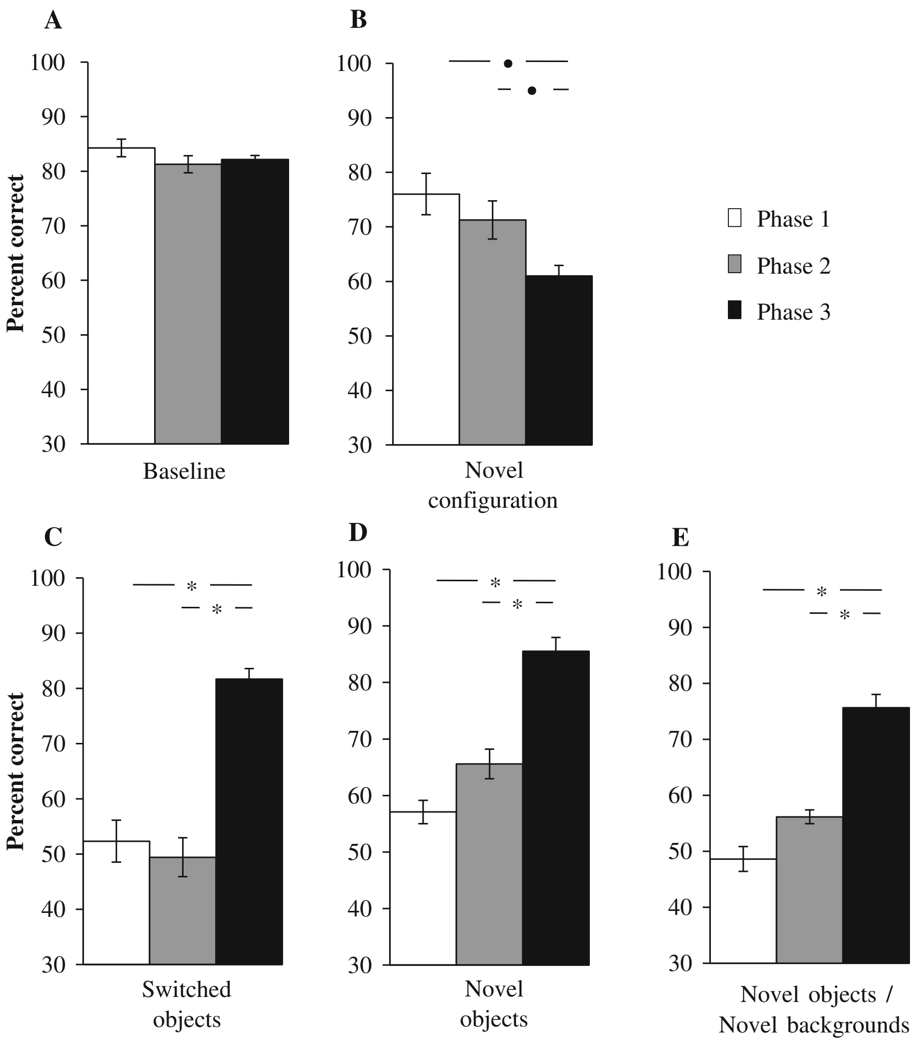

Fig. 2 Mean group accuracy in the three phases of Experiment 1 for each type of test condition; **a** Baseline, **b** Novel configuration, **c** Switched objects, **d** Novel objects, and **e** Novel objects/Novel backgrounds. The *error bars* represent the standard error. Reliable differences as inferred from Bonferroni-corrected *t* tests are indicated by the *stars*. Nonsignificant trends ($p < .006$) are indicated by the *dots*

Because long response times might reflect baboons exiting and entering the test system during a trial, trials were discarded from the data set if the response time to touch the screen exceeded 2 s. This rejection procedure removed only .7 % of all trials. Individual as well as group mean data are reported, for each test condition and phase, in Appendix 1.

To ascertain whether the baboons continued to pay attention to the training task during testing, in spite of the presence of potentially disturbing transfer stimuli, we analyzed the animals' performance in the Baseline trials of each testing phase. One-sample two-tailed *t* tests found that accuracy on Baseline trials was significantly above chance in all three of the testing phases [Phase 1 ($M = 84.25$): $t(12) = 15.95$, $p < .0001$; Phase 2 ($M = 81.27$): $t(12) = 16.92$, $p < .0001$; Phase 3 ($M = 82.15$): $t(12) = 36.10$, $p < .0001$; see Fig. 2].

The next analysis assessed how mean accuracy of the baboons varied across the three testing phases in each transfer condition (see Fig. 2) and asked, in each phase, whether performance in the transfer conditions was lower than baseline performance. For this purpose, accuracy was analyzed with a two-way repeated-measures analysis of variance (ANOVA) considering conditions (Baseline, Novel configuration, Switched objects, Novel objects, Novel objects/Novel backgrounds) and phases (Phase 1, Phase 2, and Phase 3) as factors in a 5 × 3 full-factorial design. This analysis revealed significant main effects of condition, $F(4, 48) = 34.3$, MSE = .011, $p < .0001$, $\eta_p^2 = .74$, and phase, $F(2, 24) = 35.4$, MSE = .012, $p < .0001$, $\eta_p^2 = .75$, as well as a significant condition × phase interaction, $F(8, 96) = 19.5$, MSE = .011, $p < .0001$, $\eta_p^2 = .62$.

Post hoc analyses using Bonferroni-corrected two-sample paired *t* tests (critical *p* value for 27 comparisons = .0018) showed that in Phase 1, the accuracy of Baseline trials ($M = 84.25$) was significantly higher than the accuracy of the Switched objects trials [$M = 52.34$: $t(12) = 7.37$, $p < .0001$], the Novel objects trials [$M = 57.08$: $t(12) = 7.8$, $p < .0001$], and the Novel objects/Novel backgrounds trials [$M = 48.63$: $t(12) = 11.92$, $p < .0001$]. Performance on Baseline trials, however, did not differ from performance on Novel configuration trials [$M = 76.01$), $t(12) = 2.82$, $p > .0018$]. Thus, the pattern of results in Phase 1 suggests that the baboons engaged in item-specific learning, because they failed to transfer when Novel objects were used during testing (Novel objects and Novel objects/Novel backgrounds condition). In fact, only when the same objects were presented in the same relational patterns as in training (Novel configuration trials) did they show successful transfer performance. When the same objects were presented in the opposite patterns as in training (Switched objects), the accuracy of the baboons' responding dropped dramatically.

In Phase 2, post hoc analyses continued to reveal higher performance on Baseline trials ($M = 81.27$) than on Switched objects trials [$M = 49.43$: $t(12) = 6.91$, $p < .0001$], Novel objects trials [$M = 65.60$: $t(12) = 7$, $p < .0001$], and Novel objects/Novel backgrounds trials [$M = 56.16$: $t(12) = 9.47$, $p < .0001$]. Thus, an increase in the size of the item pools, from 1 item per relational pattern to 6 items per relational pattern, did not have an appreciable effect on transfer performance. Just as in Phase 1, the baboons based their responding on the identity of the items rather than on the relation among the items, so that the accuracy of their responses was near chance levels when the identity of the items was switched or when novel items were used. Curiously, performance on the Novel configuration trials was now significantly lower than on the Baseline trials [$M = 71.27$: $t(12) = 4.36$, $p < .001$], unlike what was observed in Phase 1. This change suggests that the baboons' cognitive processing may have begun to evolve in Phase 2 as a consequence of increased set size, although relational processing was not yet established.

In Phase 3, the baboons' behavior was dramatically different than in the first two phases. Accuracy on Baseline trials ($M = 82.15$) was significantly higher than on Novel configuration trials [$M = 61.01$: $t(12) = 8.05$, $p < .0001$], but it did not differ significantly from Switched objects trials, Novel objects trials, and Novel objects/Novel backgrounds trials ($M = 81.68$, $M = 85.53$ and $M = 75.64$, respectively, all $ps > .0018$. If item-specific processing had been the strategy used in learning, then testing trials should have supported very low accuracy (Switched objects) or near chance performance (Novel objects and Novel objects/Novel backgrounds trials); because this was not the case, it is safe to conclude that relational processing took place in Phase 3. Thus, the relational structure of the stimulus arrays became salient to the baboons when the set size of the training items (60 items per relational pattern) was considerably increased.

Further post hoc analyses showed that performance on Baseline trials did not differ significantly across phases (Fig. 2a). By contrast, mean accuracy in the Novel configuration condition tended to decrease between Phase 1 ($M = 76.01$) and Phase 3 ($M = 61.01$) [$t(12) = 3.35$, $p = .0057$], and between Phase 2 ($M = 71.27$) and Phase 3 ($M = 61.01$) [$t(12) = 3.59$, $p = .0037$, Fig. 2b]. Interestingly, mean accuracy in the other three transfer conditions increased significantly between Phase 1 (Switched objects: $M = 52.34$; Novel objects: $M = 57.08$; Novel objects/Novel backgrounds: $M = 48.63$) and Phase 3 (Switched objects: $M = 81.68$; Novel objects: $M = 85.53$; Novel objects/Novel backgrounds: $M = 75.64$; all $ps < .0001$), and between Phase 2 (Switched objects: $M = 49.43$; Novel objects: $M = 65.60$; Novel objects/Novel backgrounds: $M = 56.16$) and Phase 3 (all $ps < .0001$) (Fig. 2c–e). We therefore conclude from these findings that the baboons had engaged in strong relational processing in Phase 3, because they could now make relational judgments in the two test conditions involving Novel objects (i.e., Novel objects and Novel objects/Novel Backgrounds) as well as in the Switched objects condition, in which the relational roles assigned to the objects were reversed.

Discussion

Experiment 1 disclosed a positive relationship between the increase in stimulus set size from Phases 1 through 3 and the prevalence of relational processing in our baboons' discrimination behavior in Phase 3. To account for this pattern of results, we hypothesize that presenting more different instances of the horizontal and vertical relations with a larger set of items more strongly directed the baboons' attention to the geometrical relation among the items, at the expense of their processing the individual items in the arrays. We note, however, that the baboons also received more training with continued testing; this greater amount of training might also have contributed to the increase in their relational processing. Experiment 2 addressed this issue.

Experiment 2

The transition from perceptual (Phases 1 and 2) to relational processing (Phase 3) that we observed in Experiment 1 could be due to the increase in the size of the training pool and therefore to the number of instances of each relational pattern, or it could be due to an increase in the amount of overall training on the task. Experiment 2 sought to distinguish between these rival hypotheses. It also sought to determine whether overexposure to particular stimuli would affect the relational processing that appears to have developed with the large set size that was given in Phase 3. So, the baboons were overtrained and tested in Experiment 2 using the same three stimuli that they had been given in Phase 1 of Experiment 1. If the amount of training alone accounts for the emergence of relational processing, then such processing should be further strengthened by increased training, and we should observe more accurate performance to transfer arrays containing Switched objects, Novel objects, and Novel objects/Novel Backgrounds. By contrast, if the size of the stimulus set is what matters most, then the baboons might even evidence a decrease in relational processing, thereby reverting to object-based processing, despite the increased training that they had been given, and producing less accurate performance to transfer arrays containing Switched objects, Novel objects, and Novel objects/Novel Backgrounds.

Method

Subjects, apparatus, stimuli, and general procedure

The subjects, apparatus, stimuli, and general procedure were the same as in Phase 1 of Experiment 1.

Training and testing

One month elapsed between Experiments 1 and 2. Due to this delay, baboons were initially retrained until they achieved 80 % correct in the same condition as in Phase 3 of training in Experiment 1. Average performance in the first training sessions was 76.46 %, which was statistically different from chance [$t(12) = 12.1$, $p < .0001$]. In addition, reaching the 80 % training criterion required an average of only 2.1 sessions (454 trials, range 216–864 trials). Such high performance early in training demonstrates that relational processing had been preserved between Experiments 1 and 2. After this first training period, the baboons were given a total of 30 training sessions (2,880 trials) each, as in Phase 1 of Experiment 1, and involving the same three objects (the heart shape for the horizontal pattern, the L shape for the vertical pattern, and the square-like shape for the background in both horizontal and vertical arrays). Transfer testing was conducted for 6 consecutive sessions. Each testing session contained 174 trials (150 Baseline trials plus 6 Probe trials for each of the four test conditions). For the Novel objects Probe trials and the Novel objects/Novel backgrounds Probe trials, a total of 18 stimuli that had never been shown before were used in each session.

Results and discussion

As in Experiment 1, arcsine transformations were applied to the baboons' accuracy data to correct for deviations from normality. Trials from the data set in which the time to contact the touch screen was >2 s were also discarded. This rejection procedure removed only .2 % of all trials. Appendix 2 reports the mean accuracy of the individual monkeys for the Baseline trials and for the four transfer conditions.

In a first analysis, a one-sample two-tailed t test confirmed that the percentage of correct responses in Baseline trials ($M = 96.30$) was significantly higher than 50 %, $t(12) = 30.19$, $p < .0001$. Interestingly, above-chance performance was also obtained in all of the other test conditions [Novel configuration: $M = 84.59$, $t(12) = 10.49$, $p < .0001$; Switched objects: $M = 84.66$, $t(12) = 14.94$, $p < .0001$; Novel objects: $M = 87.88$, $t(12) = 12.27$, $p < .0001$; Novel objects/Novel backgrounds: $M = 67.55$, $t(12) = 5.71$, $p < .0001$]. Above chance-performance in the test conditions using Novel objects—namely the Novel objects and Novel objects/Novel backgrounds conditions—indicates that the baboons continued to rely on relational cues to solve the task in Experiment 2. This fact is further confirmed by above-chance performance in the Switched objects condition, in which the two stimuli changed roles (the heart shapes were presented in a vertical pattern, whereas the L shapes were presented in a horizontal pattern).

The results of Experiment 2 were then directly compared to those of Phase 3 of Experiment 1, in order to assess the effect of overtraining with a small set size. This analysis involved a two-way ANOVA including conditions (Baseline, Novel configuration, Switched objects, Novel objects, Novel objects/Novel backgrounds) and Experiment (Phase 3 of Experiment 1, Experiment 2) as factors in a 5 × 2 full-factorial design. There was a significant main effect of condition, $F(4, 48) = 27.8$, $\mathrm{MSE} = .011$, $p < .0001$, $\eta_p^2 = .70$, and Experiment, $F(1, 12) = 32.7$, $\mathrm{MSE} = .013$, $p < .0001$, $\eta_p^2 = .73$. The condition × experiment interaction was also significant, $F(4, 48) = 13.8$, $\mathrm{MSE} = .012$, $p < .0001$, $\eta_p^2 = .54$ (see Fig. 3).

Post hoc analysis using Bonferroni-corrected two-tailed paired t tests (critical p value for 13 comparisons = .0038) indicated that accuracy in the Switched objects, Novel objects, and Novel objects/Novel backgrounds conditions did not differ significantly between Phase 3 of Experiment 1 and Experiment 2 (ps > .0038). However, the baboons' performance increased significantly between Phase 3 of

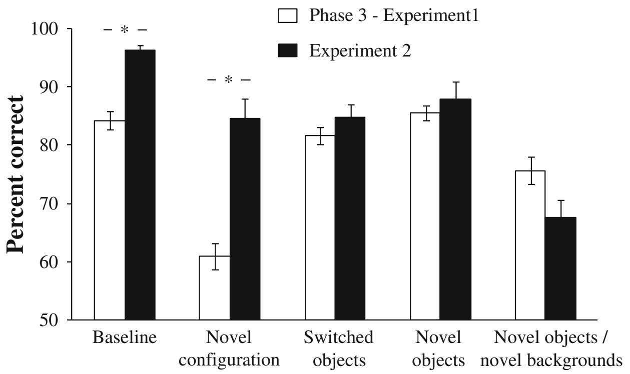

Fig. 3 Mean group accuracy in Experiment 1 (Phase 3) and Experiment 2 for each type of test condition. The *error bars* represent the standard error. Reliable differences as inferred from Bonferroni-corrected *t* tests are indicated by the *stars*

Experiment 1 and Experiment 2 for the Baseline trials [Phase 3 of Experiment 1: $M = 82.15$; Experiment 2: $M = 96.3$; $t(12) = 14.26$, $p < .0001$] as well as for the Novel configuration trials [Phase 3 of Experiment 1: $M = 61.01$; Experiment 2: $M = 84.59$; $t(12) = 6.18$, $p < .0001$]. Thus, although relational processing survived training with a reduced set size, there appeared to be some added value of such training which was restricted to the two conditions in which item processing alone could support the horizontal–vertical discrimination: Baseline trials and Novel configuration trials. This result suggests that information from the individual items, when available, can enhance performance based on relational information.

General discussion

Experiment 1 found that the type of information—item-based or relation-based—controlling our baboons' judgments of visual arrays depicting horizontal and vertical relational patterns strongly depended on the number of items in the training set. When each geometrical relation was illustrated by only a single exemplar during training (Phase 1), the baboons focused their attention on the identity of the diagnostic item—the most concrete, invariant feature of the array—thereby preventing them from appreciating the relational structure of the visual patterns. In short, they missed the forest for the trees (Soto and Wasserman 2010). Yet, after being trained with a large set of exemplars illustrating the same geometrical relations (Phase 3), the baboons effectively transferred their relational responding to arrays of entirely novel stimuli. These findings accord with other results in both the human and animal literature, indicating that training with a large number of exemplars increases the salience of the relational structure of stimuli and reduces the contribution of specific stimulus features to accurate discrimination performance.

Abstract S/D concept learning is enhanced in animals by training them with a large set of items (Castro et al. 2010; Katz and Wright 2006; Katz et al. 2002). In humans, multiple instantiations of a relation also boost transfer performance (Gick and Holyoak 1983; Homa and Vosburgh 1976; Kotovsky and Gentner 1996; Loewenstein et al. 1999; Rein and Markman 2010). Along with our current results, these convergent findings in animals and humans confirm that the number and/or variety of exemplars of a relationship plays an important role in a learner's detection and application of relational structures. This salutary effect of enriched exemplar experience may be the source of the "relational shift" that is often discussed in the human developmental literature (Gentner 1988), in which a child gradually attends less to perceived physical similarities and more to relational similarities in problem solving.

Several experimental reports with humans suggest that their processing of relations is affected by the nature of the individual items instantiating that relation. Rein and Markman (2010) found that people had more difficulty discriminating abstract relations when the role of the individual items was reversed from that arranged with the original training stimuli (as in our Switched objects condition) or when novel items were given (as in our Novel objects and Novel objects/Novel backgrounds conditions). In Gentner and Toupin (1986), children were told a story involving three characters playing specific roles and were later asked to act out the same story with new characters. Children were less able to act out the same story when the new characters looked like the characters of the first story, but had to play different roles. Similar results were obtained with adult participants who first learned a probability principle using particular objects (Ross 1987, 1989); people were less able to solve new problems using this principle when the same objects as in the training example were used during the test, but with reversed roles. Finally, computational models of analogical mapping in humans—such as the SME of Falkenhainer et al. (1989), the STAR model of Halford et al. (1994), and the LISA model of Hummel and Holyoak (1997)—also postulate that the processing of particular objects is inherent in the relational representation process.

In line with this human literature, the present study provides additional evidence that the nature of training with individual items is an important factor affecting relational processing by monkeys. Here, we used a novel procedure—overtraining with a reduced set size after relational processing had already been established—to see whether the balance between item and relational processing might be measurably altered. Interestingly, we found with this novel procedure that performance did not reliably decline on those testing trials on which relational cues alone had to be used for task solution (the Switched objects, Novel objects, and Novel objects/Novel backgrounds conditions); there was, by contrast, clear improvement in performance when item-specific information could also be used for task solution (the Baseline and Novel configuration trials) (see Fig. 3).

One possible interpretation of these results might be that the baboons shift from item-based processing to relation-based processing, and back again, depending on the availability of item-specific cues. They could, in the case of Experiment 2, use item-based information in the Baseline and Novel configuration conditions, but they would have to use relation-based information in the other three test conditions where memorizing the specific items would be useless. We therefore suspect that overtraining in Experiment 2 may have enhanced the salience of item-specific information, and that this information was combined with relational information to guide correct responding in the Baseline and Novel configuration trials, therefore promoting increased discrimination performance.

The comparison of our two experiments allows another conclusion. In Experiment 1, training set size and the total number of training trials each increased from Phase 1 to 3. In Experiment 2, the amount of training continued to increase, but enhanced control by item-specific information was found in comparison with the last test phase of Experiment 1. This finding suggests that the training set size may be a more critical variable for establishing relational processing than the duration of training per se, or the total number to training trials received.

Our conclusion that the baboons' discrimination behavior in our task was controlled by both item-specific information and relational information is supported by considerable published data. Thus, after monkeys learned a S/D or a relational matching-to-sample task (RMTS task, see Fagot et al. 2001; Fagot and Thompson 2011; for other examples in S/D tasks in pigeons or monkeys, see Wasserman et al. 1995; Wright and Katz 2006), they were given transfer trials involving new items. Accuracy on these trials was well above chance, but lower than on trials involving the original training items, suggesting that the animals' relation-based processing also included processing of the individual items. Further, Fagot and Thompson (2011) trained baboons on a RMTS task involving identity/nonidentity relations. After training, the baboons were tested with cross-mapped trials, in which one of the items illustrating the sample relation was also used to create the nonmatching relation. Performance remained above chance in these two conditions, but declined in comparison with non cross-mapped trials, further suggesting that properties of the individual items were retained and considered during processing of the abstract relations.

Item and relational processing are often presumed to be psychologically distinct (e.g., Penn et al. 2008), but the current study and other published investigations demand reconsideration of this presumption. Although our baboons appeared to focus on item-based information early in the category learning process, training with a large number of exemplars promoted a relational shift in information processing perhaps due to the increased salience of the relational structure of the stimuli in Rein and Markman's (2010) task. Nevertheless, even when relational control had been firmly established, the balance between item and relational processing could be altered by modifying the informativeness of item and relation information (see our Experiment 2 as well as Fagot and Thompson 2011). Such flexibility suggests a more intimate and intricate interplay between these sources of stimulus control in higher-order cognitive processing than many authors have envisioned—in both humans and nonhuman animals.

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Conflict of interest The authors declare that they have no conflict of interest.

Ethical Standard This research adhered to the French principles for ethical treatment for Nonhuman primates and received approval from the Provence Alpes Côte d'Azur Ethics committee for animal experimental research.

Appendix 1

See Table 1.

Table 1 Individual baboon performance in baseline and in the four transfer conditions for the three phases of Experiment 1

Subjects	Baseline	Novel configuration	Switched objects	Novel objects	No. objects No. backgrounds
Phase 1					
ARIELLE	85.83*	76.67*	56.67	46.67	60
BOBO	77.18*	60	66.67	34.48	55.17
DAN	92.93*	96.67*	53.33	53.33	43.33
DORA	95.47*	96.67*	33.33	63.33	46.67
DREAM	85.20*	73.33*	60	76.67*	40
EWINE	82.80*	86.67*	40	63.33	53.33
FANA	85.77*	80*	32.14	55.17	53.33
FELIPE	75.84*	66.67	43.33	60	50
FEYA	79.48*	62.96	64.29	37.04	51.72
FILO	86.19*	70.00*	70.00*	50	53.57
FLUTE	80.29*	51.85	60.71	65.38	35
VIOLETTE	88.27*	86.67*	50	63.33	43.33
VIVIEN	80.00*	80.00*	50	73.33*	46.67
Mean	84.25*	76.01*	52.34	57.08	48.63
Phase 2					
ARIELLE	85.35*	69.44*	38.89	63.89	52.78
BOBO	78.11*	60	61.11	66.67	72.22*
DAN	80.25*	72.22*	72.22*	69.44*	63.89
DORA	85.79*	88.89*	33.33	69.44*	66.67
DREAM	75.00*	61.11	27.78*	47.22	58.33
EWINE	79.21*	66.67	77.78*	63.89	61.11
FANA	74.79*	75.00*	38.89	55.56	48.57
FELIPE	84.49*	66.67	33.33	69.44*	48.57
FEYA	88.05*	72.22*	61.11	58.33	55.56
FILO	84.04*	77.78*	47.22	86.11*	61.11
FLUTE	90.03*	69.23*	69.44*	75.00*	52.38
VIOLETTE	70.94*	72.22*	50	61.11	41.67
VIVIEN	80.51*	75.00*	31.43	66.67	47.22
Mean	81.27*	71.27*	49.43	65.60*	56.16*
Phase 3					
ARIELLE	82.18*	66.67	77.78*	91.67*	62.86
BOBO	81.53*	72.22*	85.71*	83.33*	66.67
DAN	80.11*	66.67	76.47*	80.00*	75.00*
DORA	81.19*	63.89	80.56*	83.33*	72.22*
DREAM	84.18*	51.43	88.57*	85.71*	88.57*
EWINE	86.01*	55.56	86.11*	86.11*	83.33*
FANA	85.92*	44.44	83.33*	80.00*	72.22*
FELIPE	80.37*	52.78	69.44*	86.11*	75.00*
FEYA	77.38*	63.89	80.56*	91.67*	66.67
FILO	80.37*	69.44*	83.33*	80.00*	69.44*
FLUTE	85.71*	58.33	83.33*	88.89*	85.29*
VIOLETTE	80.36*	61.11	77.78*	91.67*	77.14*
VIVIEN	82.64*	66.67	88.89*	83.33*	88.89*
Mean	82.15*	61.01*	81.68*	85.53*	75.64*

Reliably above-chance performance for each individual and at the group level was inferred from binomial tests and one-sample t tests, respectively

* $p < .05$

Appendix 2

See Table 2.

Table 2 Individual baboon performance in baseline and in the four transfer conditions of Experiment 2

Subjects	Baseline	Novel configuration	Switched objects	Novel objects	No. objects No. backgrounds
ARIELLE	98.33*	82.35*	83.33*	100.00*	66.67
BOBO	93.27*	94.44*	75.00*	94.44*	69.44*
DAN	91.58*	96.88*	83.33*	88.89*	69.44*
DORA	97.44*	94.44*	80.00*	72.22*	68.57
DREAM	98.89*	91.67*	86.11*	91.67*	50
EWINE	98.74*	94.44*	94.12*	94.44*	77.78*
FANA	95.67*	88.89*	83.33*	97.22*	83.33*
FELIPE	90.84*	61.11	77.78*	69.44*	69.44*
FEYA	95.99*	68.57	88.89*	65.71	50
FILO	98.77*	75.00*	94.44*	91.67*	82.86*
FLUTE	98.77*	74.29*	100.00*	91.67*	75.00*
VIOLETTE	95.55*	80.56*	69.44*	91.67*	55.56
VIVIEN	98.03*	97.06*	84.85*	93.33*	60
Mean	96.30*	84.59*	84.66*	87.88*	67.55*

Reliably above-chance performance for each individual and at the group level was inferred from binomial tests and one-sample *t* tests, respectively

* $p < .05$

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