Analogical reasoning and the differential outcome effect: Transitory bridging of the conceptual gap for rhesus monkeys (*Macaca mulatta*)

Timothy M. Flemming[1], **Roger K. R. Thompson**[2], **Michael J. Beran**[1], and **David A. Washburn**[1]

[1]Department of Psychology and the Language Research Center, Georgia State University

[2]Department of Psychology, Franklin & Marshall College

Abstract

Monkeys unlike chimpanzees and humans have a marked difficulty acquiring relational matching-to-sample (RMTS) tasks that likely reflect the cognitive foundation upon which analogical reasoning rests. In the present study, rhesus monkeys (*Macaca mulatta*) completed a categorical (identity & nonidentity) relational matching-to-sample (RMTS) task with differential reward (pellet ratio) and/or punishment (timeout ratio) outcomes for correct and incorrect choices. Monkeys in either differential reward-only or punishment-only conditions performed at chance levels. However, the RMTS performance of monkeys experiencing *both* differential reward and punishment conditions was significantly better than chance. Subsequently when all animals experienced nondifferential outcomes tests, their RMTS performance levels were at chance. These results indicate that combining differential reward and punishment contingencies provide an effective, albeit transitory, scaffolding for monkeys to judge analogical relations-between-relations.

Keywords

Thompson and Oden (1996, 2000) argued that there is a 'profound disparity' between chimpanzees (*Pan troglodytes*) and monkeys in their capacity for analogical reasoning which is often referred to as a hallmark of human reasoning (e.g., Gentner, 2003; also see Premack, 1983). Thompson and Oden (2000) based this conclusion on the respective success and failure of apes and monkeys in categorical relational matching-to-sample tasks

(RMTS) that required animals to judge abstract relations (e.g., relational identity and nonidentity) in comparison stimulus pairs as being relationally the 'same' as or 'different' from that represented in the sample.

In a typical categorical RMTS task two items that are either identical (e.g., AA) or nonidentical (e.g., BC) are presented simultaneously as the relational sample against which another two pairs of relational stimuli (e.g., DD and EF) are to be compared. The animal is rewarded for choosing the comparison stimulus pair that is relationally identical to the sample. Hence, if the sample consists of an identical pair (AA) then the animal is rewarded for choosing the (DD) comparison stimulus pair that is relationally the same as the sample. Conversely, if the sample consists of a nonidentical pair (BC) then it is rewarded for choosing the (EF) pair which instantiates the same relation as the sample. In short, the animal is judging relations-between-relations to be the same or different, and this ability is arguably the cognitive foundation for analogical reasoning (Gillian, Premack & Woodruff, 1981; Thompson & Oden, 1993, 2000).

Despite their failure on 2×2 RMTS tasks, baboons performed above chance and generalize to novel stimulus sets on a relational matching task when the samples and comparison stimuli representing identity or nonidentity are comprised of not two but multiple icon arrays (Fagot, Wasserman & Young, 2001; Wasserman, Young & Fagot, 2001). Nevertheless, the monkeys' performances decrease as the number of icons within each array are systematically decreased from an initial 16 icons and are at chance levels with only two icons within each array. The pattern of results displayed by baboons (Fagot et al., 2001) and approximately 20 percent of human subjects (Young & Wasserman, 2002) reflects their learning to discriminate identity and nonidentity in the RMTS task along the perceptual dimension of relative entropy (i.e., variability vs. uniformity) rather than on a categorical basis. One striking difference between the behavior of baboons and that of human participants completing the same task is the cutoff point in entropy of the displays; baboons require a significantly greater amount of perceptual difference and sameness within displays in order to make analogical judgments. We may therefore infer that analogical thinking for a nonhuman species is more closely tied to and dependent on perception than abstract conceptualization. In fact, these entropy-dependent behaviors often regarded as "analogical" are likely perceptually grounded.

One might wonder why monkeys have consistently failed to acquire the categorical two-item RMTS task given their success on simultaneous 2-item same/different discriminations and performance levels more or less equivalent to those of chimpanzees in conditional same/different tasks (cf., Blaisdell & Cook, 2005; Flemming, Beran & Washburn, 2007; Flemming, Beran, Thompson, Kleider & Washburn, 2008; Schmidtke, Katz & Wright, 2010; Thompson, Oden & Boysen, 1997; Wright & Katz, 2006). Flemming et al. (2007) hypothesized that the monkeys' failure to acquire RMTS is due to a cognitive "disconnect" between their perceptual and categorical conceptual abilities to process relational information, wherein abstract conceptualization of relations is hampered by a natural predisposition of the animals to attend to the perceptual qualities of the stimuli. This hypothesis is supported by the evidence from preferential handling and gaze studies that abstract relational properties are implicitly more salient for chimpanzees and children even

at an early age than is the case for monkeys for whom physical elemental properties are more salient (Oden, Thompson, & Premack, 1990; Tyrrell, Stauffer & Snowman, 1991; Vauclair & Fagot, 1996). Thompson and Oden (2000) concluded from these results that monkeys are *paleologicians*; their conceptual categories are based on shared predicates – absolute and relational features bound by perceptual and/or associative similarity, whereas symbol-trained apes are *analogical* in the sense that they perceive abstract propositional similarities spontaneously.

There is good independent evidence that monkeys focus on the local properties of stimuli grouped together and, more so than chimpanzees (Fagot & Tomanaga, 1999), find it difficult to focus on the more global structures they instantiate (De Lillo et al., 2005; Dereulle & Fagot, 1998; Fagot & Dereulle, 1997; Spinozzi et al., 2003). Recent evidence from baboons implicates a local-to-global visual processing approach wherein the matching of relations is hampered. These findings are consistent with the paleological/analogical distinction. Fagot and Parron (2010) presented results that seem to indicate that variability is not a necessary component in relational matching for baboons. Using adjacent stimulus elements made of color patches, they demonstrated the first evidence for two by two item RMTS. Six baboons were trained in an RMTS task involving compound stimuli made of two identical or nonidentical color blocks. During initial training, these compound stimuli were adjoined in what could be considered one stimulus sample (rather than a pair of images) and two choice stimuli (rather than two pairs of images), making it striking similar to an identity MTS task. In subsequent experimental phases, gaps between stimulus elements were introduced in incrementally larger sizes, effectively creating a true two by two item RMTS. The performance of baboons, which initially exceeded levels of chance, collapsed with increases in gap size between the stimulus elements, eventually falling to chance accuracy with a gap of just 30 pixels. This effect, which disappeared after 4,000 training trials, provided suggestive evidence for relational mapping of these identity/nonidentity pairs. Gaps of 60 pixels or larger between stimulus elements resulted in chance performance throughout the study. Fagot and Parron (2010) believed that this ability to match relations by monkeys had been previously masked due to local processing of stimuli that hindered monkeys' ability to perceive the stimuli as pairs rather than independent objects.

In order to make explicit same/different judgments of abstract relations as in analogical judgments (2×2 RMTS), one must represent the abstract concepts in some way. Little is known of the modality of such representations for nonhuman animals but one possibility is that the provision of physical symbols affords chimpanzees and children, if not monkeys, the opportunity to encode abstract same-different relations as iconic representations thereby functionally reducing the RMTS task to a covert physical matching problem (Thompson & Oden, 1996, 2000; Thompson, Oden & Boysen, 1997). Symbol systems appear to provide apes and humans the representational scaffolding for manipulation and expression of propositional knowledge in relational matching-to-sample (RMTS) and related nonverbal analogy tasks (Gillan, Premack & Woodruff, 1981; Oden, Thompson & Premack, 2001). However, there is no evidence as yet that physical conditional cues associated with specific conceptual relations similarly acquire symbolic meaning for monkeys (Flemming et al., 2008).

In the present study we examined the possibility that differential expectancies of reward and punishment associated with specific relational matching choices might provide a functional alternative 'scaffolding' effect for attention to and representation of abstract relations analogous to that of conceptual symbols for ape and child. Our choice of the differential outcomes procedure was prompted by evidence for differential outcome effects (DOE) in which rates of acquisition and terminal accuracy are increased when response outcomes are inequitable across different stimulus types (e.g., Meyer, 1951; Trapold, 1970). Evidence for the strength of the DOE in conditional learning procedures has been provided for rats (Ludvigson & Gay, 1967), pigeons (Kelley & Grant, 2001) and for young children in classroom settings (Estevez, Fuentes, Mari-Beffa, Gonzalez, & Alvarez, 2001; Maki-Kahn, Overmier, Delos & Gutmann, 1995). However, this effect is not ubiquitous, with some reports of mixed results for pigeons (Brodigan & Peterson, 1976; Williams, Butler & Overmier, 1982).

To illustrate the DOE, Trapold (1970) rewarded rats differentially with a food pellet or sucrose solution for bar presses across several schedules of reinforcement. Subjects were required to choose one of two bars in response to either a tone or light discriminative stimulus and commit to 10 responses on that bar in order to end a trial after the initiation of tone or light. Rats consistently made more correct responses when a different reinforcer was used for the two separate stimulus-response components than when the same reinforcer was used for each. Trapold concluded that the rats had developed different expectancies for food and for sucrose which in turn produced distinctive stimulus properties allowing for a similar function as any other stimuli.

Beyond single stimuli, human judgments of relations have been shown to be enhanced by differential outcome procedures (Estevez et al., 2007). Participants viewed mathematical "greater than" and "less than" relational statements (e.g. 5.88 > 5.31) and were asked to indicate whether the statement was true or false. Upon their choice, participants were given one of two different outcomes: a melodic tone or the word "great." Response times were shorter for those participants in the differential outcomes condition. Further, with increased task difficulty (the inclusion of two negative numbers) participants in the differential outcomes condition not only showed improved response times, but also performed at rates of higher accuracy.

We hypothesized that a similar DOE might be obtained also with abstract relational stimuli in the RMTS task to instantiate a novel rule: analogical-relational matching. We attempted to emphasize the conceptual relational nature of the stimulus pairs over the physical properties of physical elements within pairs by consistently associating different hedonic values with each exemplar of a given relation following correct matching responses. Thus, not unlike matching via reinterpreted symbols for *same* and *different*, it is perhaps the case that for monkeys, hedonic valences alone may serve a similar function in matching.

In this experiment, we presented rhesus monkeys with a relational matching-to-sample (RMTS) task with pairs of identical/non-identical images serving as the sample and match stimuli. A given monkey was tested in 1 of 3 conditions: Differential reward (DR), differential punishment (DP), and differences in both reward and punishment (DB). With the

inclusion of the *both* condition, we were able to assess the relative magnitude in differential strength required to observe the DOE. After completing trials under differential outcome conditions, monkeys then completed sessions with non-differential outcomes to determine the retention or permanence of these learned choices. Finally, monkeys returned to their original DR/DP/DB condition to investigate a possible rebound effect for choice behavior and/or dependence on these conditions to guide behavior.

Method

Subjects

Six male rhesus monkeys (*Macaca mulatta*) aged 5 to 20 years and housed at Georgia State University's Language Research Center in Atlanta, GA, served as subjects for all phases of this experiment. All monkeys had extensive testing histories responding via joystick-guided cursor movement to computer-generated stimuli presented on a monitor (Washburn, Rumbaugh & Richardson, 1992).

Three of the monkeys previously participated in relational matching-to-sample tasks (e.g., Flemming et al., 2008). The remaining three monkeys were naïve to relational tasks. Monkeys were pseudo-randomly assigned to one of three differential-outcome testing conditions: differential reward only (DR), differential punishment only (DP), and both differential reward and punishment (DB) assigned. Monkeys that had previously participated in the Flemming et al. (2007, 2008) tasks were each assigned to one of the outcome conditions as was one other monkey in that same condition from the naïve group. Monkeys were each then randomly assigned one relation (identity vs. nonidentity) to be emphasized for the entire duration of the differential outcome sessions as described below.

Each monkey was tested while individually housed in its home enclosure. Monkeys had continuous access to the computerized program for blocks of time ranging from 4 to 8 hours, completing a total of 40 200-trial blocks (total of 10 daily sessions per condition per phase per animal over the course of approximately 12 weeks). During testing, the computer program controlled all stimulus presentations and reward delivery. No animals were food or water deprived for any portion of testing; all procedures were approved by the Institutional Animal Care and Use Committee of Georgia State University.

Design and Procedure

Monkeys first completed 2,000 trials in their pseudo-randomly assigned DO condition, then two sets of test sessions (2,000 trials each) with equalized outcomes, and subsequently another 2,000 trials in their originally assigned DO condition. This between-subjects ABBA design was favored over a within-subjects design to eliminate concern of carryover effects between differential outcome experimental conditions. Successes by monkeys in subsequently presented conditions would be confounded with experience rather than experimental condition alone.

Within each trial, monkeys first saw a sample pair instantiating either the identical or nonidentical relation (AA or BC). Bringing a joystick-guided cursor in contact with that pair revealed two choice pairs: a novel identical pair (DD) and novel nonidentical pair (EF).

Monkeys then selected a choice by contacting the pair with the cursor. A total of 5000 multicolored clipart stimuli comprised the stimulus pool from which all pairs were constructed. Stimuli consisted of session-unique clipart images so that after inclusion in one pair, either the sample pair or the choice pairs, each stimulus was discarded and not used in any other relational pair throughout the testing session. Thus, throughout the course of all testing phases, a given stimulus could appear twice within a phase, but never twice within a daily testing session.

Outcome schedules—In the first phase (A1), monkeys completed RMTS trials in 1 of 3 differential outcome conditions. Two monkeys (Willie and Luke) were assigned to differential reward-only (DR), two monkeys (Hank and Han) to differential punishment-only (DP), and two monkeys (Gale and Obi) to both differential outcomes (DB). Each monkey was also randomly assigned to either identity or nonidentity as their relation of *better* hedonic value. For example, if assigned to identity, the better (i.e. great number of pellets) payoff followed correct choices only if the sample was identical and choice pair selected was identical.

Rewards differed in magnitude of pellets delivered for correct responses. In the differential reward only (DR) condition, correct choices of the assigned higher hedonic relation resulted in the delivery of 4 pellets whereas correct choices of the other relation resulted in the delivery of only 1 pellet. Any incorrect match resulted in a 5s inter-trial interval (ITI) for both relations.

Punishments (penalties) differed in the duration of ITI following incorrect choices. In the differential punishment only (DP) condition, correct responses resulted in the delivery of just 1 pellet regardless of relation type. If monkeys chose incorrectly on a trial of the more heavily punished relation (e.g., choosing a nonidentical pair in the presence of an identical sample pair) they experienced a 45 s ITI as compared to a 10 s ITI following the incorrect selection of the less heavily punished relation.

In the *both* (DB) condition, correct responses to the emphasized relation led to delivery of 4 food pellets whereas incorrect responses to the other relation resulted in only 1 pellet. Additionally, incorrect responses to the emphasized relation were followed by a 45 s ITI and incorrect responses to the other relation were followed by a 10 s ITI. Figure 1 shows an example depiction of the DB trial type (*same* emphasized).

In the next phase (B1), monkeys completed all trials with equalized outcome (EO1). A condition with equalized outcome following a potential DOE for all six animals was conducted to examine possible carry-over effects from Phase A1 including the possibility that any observed DOE effect from Phase 1 might facilitate continued relational matching in the absence of differential outcome procedures. It is perhaps that the DOE results in a lasting learned rule for the RMTS. In this phase, all correct choices resulted in delivery of 1 pellet while incorrect choices resulted in a 10 s ITI.

Following Phase B1, all six monkeys completed an additional phase of equalized outcome (Phase B2) where correct choices resulted in the delivery of 4 pellets (EO 4) in contrast to

only a single pellet to determine if any observed effects in Phase 1 may be attributed to the sheer magnitude of the larger reward *per se* as opposed to a true differential outcome effect.

In the final phase (A2), monkeys completed a second set of 2,000 trials in their originally assigned differential outcome condition from A1. This phase was conducted to examine possible rebound effects from potential loss of the DOE in phases B1 and B2.

Results

Experimental Phase A1 – Differential Outcome

In the DB condition (Phase A1), in which both reward magnitude and punishment duration differed across relations, both Gale and Obi performed significantly above chance with accuracies of 84.1% and 86.3% respectively (Gale, $z = 15.25$; Obi, $z = 16.23$, $ps < .01$). This marks unique success in an RMTS task by rhesus monkeys.[1] Symmetrical performance was also observed for both monkeys, indicating that performance on *same* and *different* trial types was equally high (see Figure 2 for learning curves for this experimental phase).

In DR and DP conditions, no effects due to differential outcome were observed. Luke, Han and Hank completed the final 500 trials of their sessions with an average accuracy of 50.8% (chance = 50%; see Table 1). One monkey performed significantly better than chance in the DR condition (73.4%). However, this was due to an asymmetrical selection[2] of the emphasized relation only (Willie, $z = 10.42$, $p < .01$). This monkey chose the correct relation significantly above chance levels only when the sample was of the assigned emphasized relation. Of the trials that were completed correctly, 85.2% were matches of *same* to *same* relation, rather than distributing his responses evenly, χ^2 (1, N=1424) = 400.73, $p < .01$. Performance for all other monkeys was symmetric in the DR and DP conditions (see Table 1).

Experimental Phases B1 & B2 – Equalized Outcome

In both equalized outcome (EO 1 and EO 4) phases, regardless of pellet magnitude, performance did not differ significantly from chance (50%) for any monkey. Symmetrical performance was observed for every monkey. See Table 1 for a summary of results.

Experimental Phase A2 – Differential Outcome

In Phase A2, a pattern of results similar to A1 was observed. In DR and DP conditions, no effects due to differential outcome were observed. Willie, Han and Hank completed the final 500 trials of their sessions with an average accuracy of 51.8% (chance = 50%; see Table 1).

---

[1]Monkeys who have previously performed similar RMTS tasks with equalized outcome in Flemming et al. (2007, 2008) were Willie, Gale, and Hank. All other monkeys were completely naïve to RMTS tasks. Important to note is the fact that of the experienced monkeys, although none had prior success on similar tasks, 1 monkey now performed at levels above chance. Additionally, 1 naïve monkey (Obi) performed at levels above chance in the current task, decreasing the possibility that prior performance on similar tasks solely accounted for current task performance.

[2]Assessing the possibility of asymmetric performance on *same* versus *different* trials, we conducted post hoc analyses examining performance for all same and different trials that were completed correctly. Achieving levels of significance (above chance) was possible by garnering higher success rates of one trial type over another. One could potentially succeed on a very high percent of only one trial type and perform at or below chance levels on the other, still providing overall levels of performance significantly above chance.

While one monkey in the DR condition performed at a level significantly chance, 75.1% (Luke, $z = 11.23$, $p < .01$), his performance was not symmetrical and therefore an artificial reflection of successful relational matching χ^2 (1, N=1424) = 327.53, $p < .01$. Performance for all other monkeys was symmetric in the DR and DP conditions (see Table 1).

In the DB condition (A2), in which both reward magnitude and punishment duration differed, both Gale and Obi performed significantly above chance with accuracies of 87.5% and 89.2% respectively (Gale, $z = 16.68$; Obi, $z = 17.49$, $ps < .01$). Symmetrical performance was also observed for both monkeys.

Confirmatory independent follow-up tests

In order to address concerns that only two monkeys showed the DOE in the relational matching task, we replicated the same pattern of results reported above. Three randomly selected individuals completed 2,000 trials in one other differential condition not previously experienced. This test was given seven months after all previous data collection had ended. Obi (originally approximately 86% correct in the DB-*both* condition) correctly completed only 53% of trials in the reward-only condition. Gale (originally approximately 84% correct in the DB-*both* condition) correctly completed only 49% of trials in the punishment-only condition. Hank (originally only 51 % correct in the DP-*punishment only* condition) correctly completed 82% of trials in the DB-*both* condition. This pattern of results replicates findings from the originally presented ABBA design. As a group, these three monkeys (Hank, Gale and Obi) performed significantly better in the DB-*both* ($M = 421.33$, $SD = 10.07$) condition than in either of the single (DR or DP) differential outcome ($M = 255.33$, $SD = 10.02$) conditions; $t(4) = 20.24$, $p < 0.01$.

Discussion

Results from the present experiment provide evidence that macaque monkeys (*Macaca mulatta*) are capable of making explicit categorical-conceptual two-item (2×2) judgments of analogical relations (*same* or *different*) between relations (*identity* or *nonidentity*) with trial unique stimulus pairs. The results also indicate that mechanisms other than global attentional focus (i.e., Fagot & Parron, 2010) may operate to control the employment of analogical reasoning via a matching of hedonic valence. With differential scaffolding provided, rhesus monkeys seemed to have bridged the conceptual gap oft ascribed in their representational abilities (Flemming et al., 2007; Premack, 2010; Thompson & Oden, 1993, 2000). Importantly, these results extend the evidence for differential outcome effects (DOE) beyond conditional discriminations involving perceptual physical and relational stimuli to those involving categorical relations-between-relations (cf., Brodigan & Peterson, 1976; Friedrich & Zentall, 2010; Schmidtke, Katz & Wright, 2010; Trapold, 1970).

As hypothesized, differential outcomes allowed for the expression of the requisite trial-unique abstract conceptual skills forming a cognitive foundation for analogical reasoning. However, contrary to our expectation, these skills depended upon sustained differential outcomes and did not transfer under conditions of nondifferential reinforcement and punishment. No monkey successfully completed RMTS trials at levels above chance with equalized outcome (EO) receiving 1 pellet. Hence we conclude that differential outcomes

were likely the cause of success in the *both* (DB) condition of phase A1. Moreover, given the lack of the animals' success on trials in which they received 4 pellets, we can rule out the possibility that heightened performance in Phase A1 (DB) is attributable to simple reward magnitude effects resulting in a preference for one type of trial configuration.

Recent reports provide evidence for differential outcome-faciliated *same/different* concept learning in pigeons (Friedrich & Zentall, 2010; Schmidtke, Katz & Wright, 2010). Friedrich and Zentall (2010) trained pigeons on a conditional discrimination task that involved either differential probability of reinforcement or differential responding (via key pecks) to comparison stimuli. Differential outcomes in two conditional discriminations effectively formed two stimulus classes. With the institution of a differential outcome system of equalized hedonic value, the authors stated that arbitrary differential properties of outcomes could effectively serve as choice comparison cues. Although Friedrich and Zentall (2010) illustrated an enhancement in speed of acquisition of same/different concepts, it did not address the learning of a novel rule via differential outcome procedures as in the present study.

Rather than being explicitly guided by sameness and difference of sample and target pairs, monkeys likely used established hedonic valence associated with *same* and *different* pairs to guide their choice behavior. Each relation is uniquely mapped onto a specific positively- or negatively-hedonic outcome facilitating the process of a comparison of these relations. This is not the case when a single hedonic value is associated with both relationships. Differential outcome procedures such as those instantiated in the current study may provide the means for multiple representations of relational-conceptual stimuli and the subsequent mapping of relations-between-relations. That the monkeys in the current study could not retain the analogical rule learned with differential outcomes further suggests that the hedonic cognitive incentives in the absence of differential outcomes (reward & punishment) are no longer sufficient to maintain responding at the global conceptual relational level in the face of its cognitive costs (i.e., retention of sequential matches). Hence the monkeys revert to the cognitively less demanding default perceptually grounded level of attention to local/physical properties stimuli. The intermittent 50% reinforcement rate associated with such a strategy presumably is sufficient to maintain execution of responses to sample and comparison stimuli without regard to their abstract categorical/conceptual content.

We assume that the monkeys' default attentional focus under nondifferential reinforcement and punishment is focused the perceptual properties (predicates) of individual stimuli instantiating the experimental stimulus pairs (i.e., Thompson & Oden, 2000). We further assume that monkeys learn stimulus-type specific representations or expectancies of the differential reinforcing/punishing events. Berridge and Robinson (2003) discuss these reward expectations as a form of cognitive incentive wherein hedonic expectations serve as a basis for motivation. Whereas Fagot and Parron (2010) encouraged an explicit shift in attentional focus via reduced spatial grouping demands, we find with the current data yet another possibly complimentary, if not unique, mechanism via a mapping and comparison of hedonic valence by which relational matching can be accomplished by monkeys. Although there is no evidence that differential outcomes serve as proto-symbolic cues oft-cited as integral to analogical reasoning (Oden et al., 1990; Premack, 1983; Thompson & Oden,

1993), it appears that differential outcomes may operate analogously thereby bridging the previous seemingly uncrossable conceptual gap in analogical reasoning by old-world monkeys.

Acknowledgments

References

Berridge KC, Robinson TE. Parsing reward. TRENDS in Neurosciences. 2003; 26:507–514. [PubMed: 12948663]

Brodigan DL, Peterson GB. Two-choice conditional discrimination performance of pigeons as a function of reward expectancy, prechoice delay, and domesticity. Animal Learning & Behavior. 1976; 4:121–124. [PubMed: 964435]

Blaisdell AP, Cook RG. Two-item same-different concept learning in pigeons. Learning & Behavior. 2005; 33:67–77. [PubMed: 15971494]

Deruelle C, Fagot J. Visual search for global/local stimulus features in humans and baboons. Psychonomic Bulletin & Review. 1998; 5:476–481.

De Lillo C, Spinozzi G, Truppa V, Naylor DM. A comparative analysis of global and local processing of hierarchical visual stimuli in young children (*Homo sapiens*) and monkeys (*Cebus apella*). Journal of Comparative Psychology. 2005; 119:155–165. [PubMed: 15982159]

Estevez AF, Fuentes LJ, Mari-Beffa P, Gonzalez C, Alvarez D. The differential outcome effect as a useful tool to improve conditional discrimination learning in children. Learning and Motivation. 2001; 32:48–64.

Estevez AF, Vivas AB, Alonso D, Mari-Beffa P, Fuentes LJ, Overmier JB. Enhancing challenged students' recognition of mathematical relations through differential outcomes training. The Quarterly Journal of Experimental Psychology. 2007; 60:571–580. [PubMed: 17455067]

Fagot J, Deruelle C. Processing of global and local visual information and hemispheric specialization in humans (*Homo sapiens*) and baboons (*Papio papio*). Journal of Experimental Psychology: Human Perception and Performance. 1997; 23:429–442. [PubMed: 9104003]

Fagot J, Parron C. Relational matching in baboons (*Papio papio*) with reduced grouping requirements. Journal of Experimental Psychology: Animal Behavior Processes. 2010; 36:184–193. [PubMed: 20384399]

Fagot J, Tomonaga M. Global and local processing in humans (*Homo sapiens*) and chimpanzees (*Pan troglodytes*): Use of a visual search task with compound stimuli. Journal of Comparative Psychology. 1999; 113:3–12.

Fagot J, Wasserman EA, Young ME. Discriminating the relation between relations: The role of entropy in abstract conceptualization by baboons (*Papio papio*) and humans (*Homo sapiens*). Journal of Experimental Psychology: Animal Behavior Processes. 2001; 27:316–328. [PubMed: 11676083]

Flemming TM, Beran MJ, Washburn DA. Disconnect in concept learning by rhesus monkeys: Judgment of relations and relations-between-relations. Journal of Experimental Psychology: Animal Behavior Processes. 2007; 33:55–63. [PubMed: 17227195]

Flemming TM, Beran MJ, Thompson RKR, Kleider HM, Washburn DA. What meaning means for same and different: Analogical reasoning in humans (*Homo sapiens*), chimpanzees (*Pan troglodytes*), and rhesus monkeys (*Macaca mulatta*). Journal of Comparative Psychology. 2008; 122:176–185. [PubMed: 18489233]

Friedrich AM, Zentall TR. A relational differential outcomes effect: Pigeons can classify outcomes as "good" and "better". Animal Cognition. 2010; 13:359–365. [PubMed: 19779744]

Gentner, D. Why we're so smart. In: Gentner, D.; Goldin-Meadow, S., editors. Language in mind: Advances in the study of language and thought. Cambridge, MA: MIT Press; 2003. p. 195-235.

Gillian DJ, Premack D, Woodruff G. Reasoning in the chimpanzee: I, Analogical reasoning. Journal of Experimental Psychology: Animal Behavior Processes. 1981; 7:1–17.

Kelley R, Grant DS. A differential outcomes effect using biologically neutral outcomes in delayed matching-to-sample with pigeons. The Quarterly Journal of Experimental Psychology. 2001; 54B: 69–79.

Ludvigson HW, Gay RA. An investigation of conditions determining contrast effects in differential reward conditioning. Journal of Experimental Psychology. 1967; 75:37–42. [PubMed: 6065836]

Maki-Kahn P, Overmier JB, Delos S, Gutmann AJ. Expectancies as factors influencing conditional discrimination performance of children. Psychological Record. 1995; 45:45–71.

Meyer DR. The effects of differential rewards on discrimination reversal learning by monkeys. Journal of Experimental Psychology. 1951; 41:268–274. [PubMed: 14850642]

Oden DL, Thompson RKR, Premack D. Infant chimpanzees spontaneously perceive both concrete and abstract same/different relations. Child Development. 1990; 61:621–631. [PubMed: 2364739]

Oden, DL.; Thompson, RKR.; Premack, D. Can an ape reason analogically? Comprehension and production of analogical problems by Sarah, a Chimpanzee (Pan troglodytes). In: Gentner, D.; Holyoak, KJ.; Kokinov, BN., editors. Analogy: Theory and phenomena. Cambridge, MA: MIT Press; 2001. p. 472-497.

Premack D. Animal cognition. Annual Review of Psychology. 1983; 34:351–362.

Premack D. Why human are unique: Three theories. Perspectives on Psychological Science. 2010; 5:22–32.

Schmidtke KA, Katz JS, Wright AA. Differential outcomes facilitate same/different concept learning. Animal Cognition: online first. 2010

Spinozzi G, De Lillo C, Truppa V. Global and local processing of hierarchical visual stimuli in tufted capuchin monkeys (*Cebus apella*). Journal of Comparative Psychology. 2003; 117:15–23. [PubMed: 12735359]

Thompson, RKR.; Oden, DL. "Language training" and its role in the expression of tacit propositional knowledge in chimpanzees (*Pan troglodytes*). In: Roitblat, HL.; Herman, LM.; Nachtigall, PE., editors. Language and communication: Comparative perspectives. Hillsdale NJ: Erlbaum Associates; 1993. p. 365-384.

Thompson RKR, Oden DL. A profound disparity revisited: Perception and judgment of abstract identity relations by chimpanzees, human infants, and monkeys. Behavioural Processes. 1996; 35:149–161. [PubMed: 24896027]

Thompson RKR, Oden DL, Boysen ST. Language-naïve chimpanzees (*Pan troglodytes*) judge relations between relations in a conceptual matching-to-sample task. Journal of Experimental Psychology: Animal Behavior Processes. 1997; 23:31–43. [PubMed: 9008861]

Thompson RKR, Oden DL. Categorical perception and conceptual judgments by nonhuman primates: The paleological monkey and the analogical ape. Cognitive Science. 2000; 24:363–396.

Trapold MA. Are expectancies based upon different positive reinforcing events discriminably different? Learning and Motivation. 1970; 1:129–140.

Tyrrell DJ, Stauffer LB, Snowman LG. Perception of abstract identity/ difference relationships by infants. Infant Behavior and Development. 1991; 14:125–129.

Vauclair J, Fagot J. Categorization of alphanumeric characters by baboons (*Papio papio*): Within and between class stimulus discrimination. Current Psychological Cognition. 1996; 15:449–462.

Washburn DA, Rumbaugh DM, Richardson WK. The Language Research Center's computerized test system for environmental enrichment and psychological assessment. Contemporary Topics. 1992; 31:11–15. [PubMed: 11538192]

Wasserman EA, Young ME, Fagot J. Effects of number of items on the baboon's discrimination of same from different visual displays. Animal Cognition. 2001; 4:163–170. [PubMed: 24777506]

Wright AA, Katz JS. Mechanisms of same/different concept learning in primates and avians. Behavioural Processes. 2006; 72:234–254. [PubMed: 16621333]

Young ME, Wasserman EA. Detecting variety: What's so special about uniformity? Journal of Experimental Psychology: General. 2002; 131:131–143. [PubMed: 11900100]
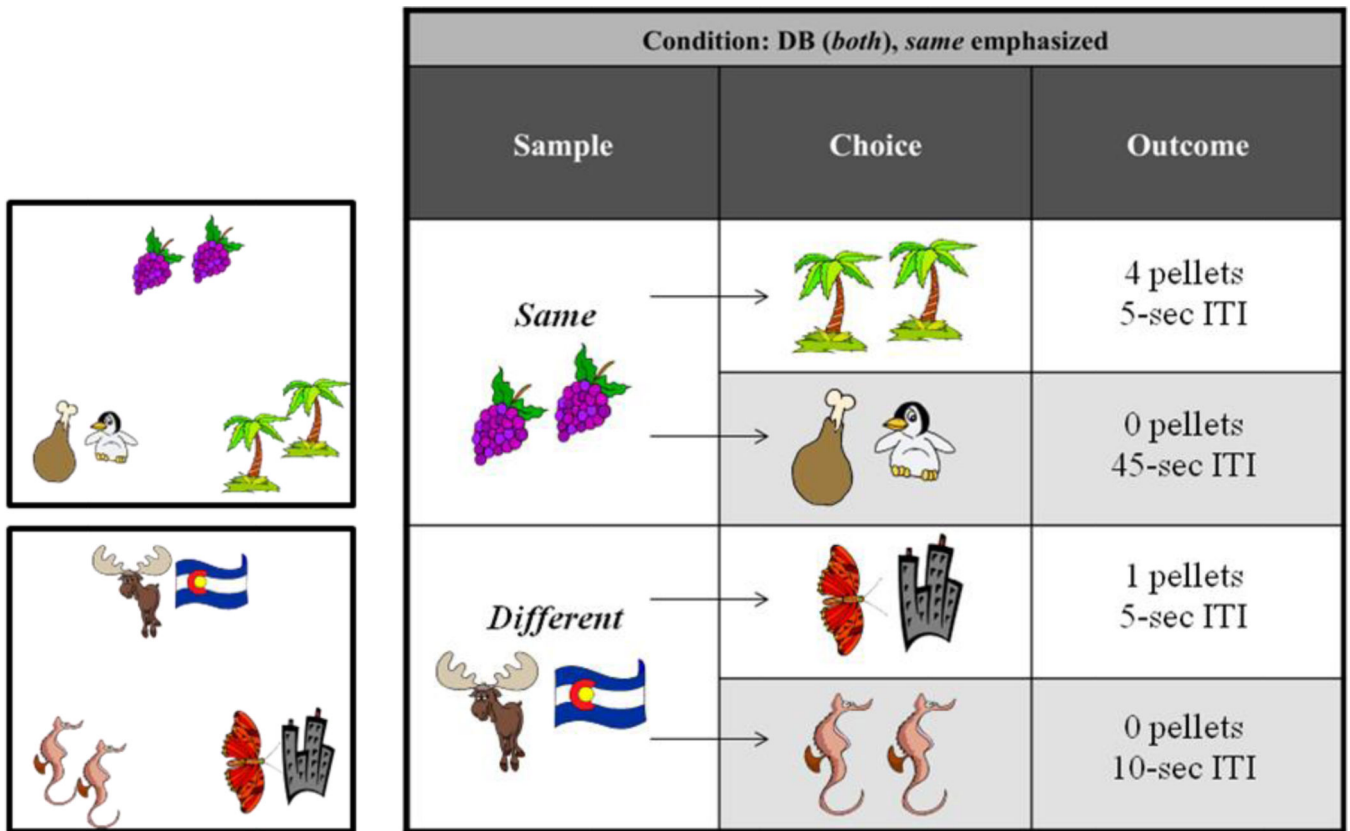
Figure 1.
Depiction of trial choices and outcomes from the DB (both) condition with *same* emphasized. Screen captures (left) represent stimulus-pair arrangement as the monkey would see; sample pair is centered along top edge and choice pairs are located in lower corners. Stimulus images depicted are simplified for publication purposes. Trial-unique multi-colored clipart images were used throughout all phases of this project.
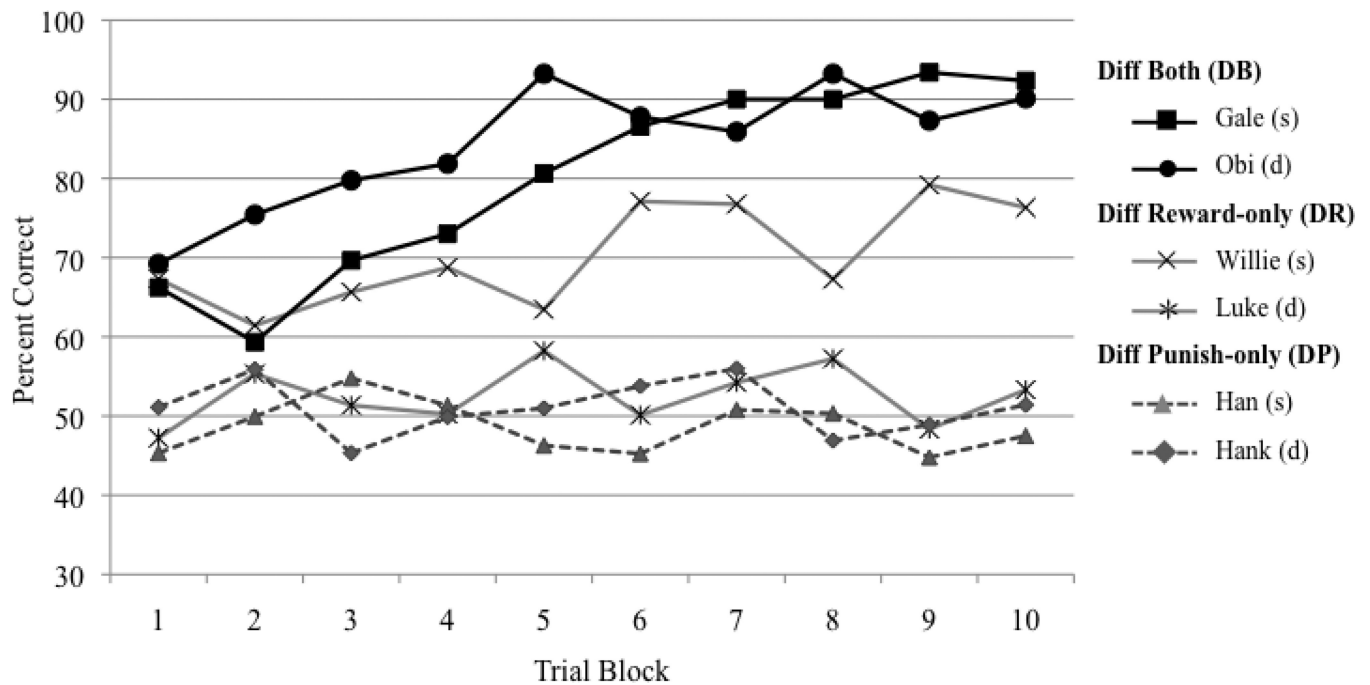
Figure 2.
Performance across trial blocks for experimental condition. Percent correct was calculated for each individual out of blocks of 200 trials (1 daily testing session) of the full set of 2000 trials in their assigned experimental condition. Emphasized relation for each monkey appears in parentheses after their name. Horizontal dashed line represents a level of responding consistent with chance (50%).

Table 1

Performance Summaries by Experimental Phase

Phase Condition and subject	% correct	z	% emphasized of correct trials	χ^2
A1 – Differential Outcome				
Reward Only (DR)				
Willie (*s*)	73.4	10.42*	85.2	400.73*
Luke (*d*)	53.9	1.74	50.8	.12
Punish Only (DP)				
Han (*s*)	47.5	−1.03	52.2	.83
Hank (*d*)	51.1	.49	47.6	.58
Both (DB)				
Gale (*s*)	84.1	15.25*	52.4	1.09
Obi (*d*)	86.3	16.23*	53.0	2.78
B1 – Equalized Outcome 1				
Willie (*s*)	46.9	−1.39	50.7	.08
Luke (*d*)	51.1	.49	50.1	.01
Han (*s*)	52.5	1.12	47.6	1.05
Hank (*d*)	51.2	.49	51.7	.47
Gale (*s*)	52.7	1.21	49.5	.03
Obi (*d*)	54.2	1.83	46.4	2.64
B2 – Equalized Outcome 4				
Willie (s)	52.1	.94	49.2	.12
Luke (d)	48.1	−.76	48.3	.47
Han (s)	52.7	1.21	47.9	.76
Hank (d)	54.0	1.74	46.2	2.99
Gale (s)	50.3	.13	46.9	2.00
Obi (d)	46.2	−1.65	50.23	.01
A2 – Differential Outcome				
Reward Only (DR)				
Willie (*s*)	54.2	−1.83	53.5	2.62
Luke (*d*)	75.1	11.23*	81.7	327.53*
Punish Only (DP)				
Han (*s*)	53.0	1.3	50.7	.07
Hank (*d*)	48.3	−.67	48.6	.34
Both (DB)				
Gale (*s*)	87.5	16.68*	49.1	.26
Obi (*d*)	89.2	17.49*	52.4	1.89

Note. Emphasized relation is represented after subject name in parenthesis (*s = same; d = different*). Percent correct was calculated from the last 500 of 2000 total trials. These percentages reflect the same pattern of results for the entire block of 2000 trials. Within the last 500 trials, learning curves had reached a threshold and remained at levels approximate to the percent correct reported above. Binomial tests were run only on this last

quartile of the data for representative statistical results that would not otherwise have been reflected with the full 2000 trials. Data for symmetry (% emphasized and corresponding χ^2) analyses were taken from all correct trials out of 2000.

*
p < .01.