Learn Behav (2016) 44:295–302
DOI 10.3758/s13420-016-0215-4

Response to stimulus relations by a dog (*Canis lupus familiaris*)

K. Marinka Gadzichowski[1] · Kelly Kapalka[1] · Robert Pasnak[1]

Published online: 5 February 2016

Abstract A malamute-husky mixed-breed dog was trained to distinguish one object that differed from three others that were identical to each other. The dog progressed rapidly after an effective shaping procedure, requiring 37 training sessions to master 20 such problems to a criterion of 90 %. The dog subsequently scored 80 % correct on the first trials with new problems that required a reversal of previously correct choices. The dog then scored 70 % correct on his first trials with 20 new problems composed of entirely new objects. Both performances are far above chance. Consequently, we conclude that choosing the odd or least numerous object in a group is within the capacity of the domestic dog.

Keywords Oddity · Numerosity · Stimulus relationships · Animals

This paper investigates the ability of a common carnivore to learn the concept of oddity. The ability to consistently select the least numerous or "odd" object in a group requires an understanding of the relationship between the stimuli in question. The person or animal subject must determine which of the objects presented is the "odd" object (i.e., which object is different from the others). Thus, if an oval bead and three round beads are presented, the oval bead is "odd." But if three oval beads and one square bead are presented, the square bead is odd rather than one of the oval beads. (i.e., the object that had previously been odd was now non-odd). The key point is that such problems cannot be solved by relying on the perceptual properties of any particular stimulus; rather, the *relationship* between all stimuli must be determined. To solve one such problem, an animal (or human) need simply learn a concrete characteristic of the correct stimulus that differentiates it perceptually from others in the group. To solve a few such problems, the animal or human subject need merely learn a few such perceptual distinctions. But to be able to solve many such problems, upon *first* encountering them, the subject can rely only upon the relationship between the stimuli and select the stimulus that is correct in terms of that relationship. In this case, that would be the odd object. There would be no opportunity to learn, for each problem, a concrete characteristic that identified the correct choice. This is what makes such problems important; responses must be based on a consistent relationship between stimuli rather than on a different perceptual stimulus characteristic for each problem.

Bailey and Thomas (1998) framed the issue in the following manner: The oddity concept task is representative of what has been defined as a relative class concept as opposed to absolute class concept (e.g., Thomas, 1980). The defining features of absolute class concepts are inherent in each discriminandum (e. g., "tree," water," and a person; Herrnstein, Loveland, & Cable, 1976), but relative properties such as "oddity" are not inherent in the discriminandum that represents a relative class concept (p. 333). Although these authors and many others have considered consistent mastery of problems representing the oddity principle to be a concept, it can more conservatively be considered to be a response to perceptual stimulus relationships, which is the approach we take in this paper. We recognize that the response to perceptual stimulus relationships might actually be based on relative frequency of the stimuli in any group, which fits the definition of a relational response equally well. A stimulus may be odd or unique in any perceptual dimension. Hence, on the simplest

✉ K. Marinka Gadzichowski
kgadicho@gmu.edu

[1] George Mason University, Fairfax, VA 22030, USA

level, consistently distinguishing single objects from other objects that are more numerous on some perceptual dimension is important because it involves response to the relationship of the stimuli (i.e., relational responding). Between the ages of 4 and 6 years and without formal instruction, humans generally become capable of understanding problems that involve distinguishing one object that differs from several others by the stimulus dimension of color, shape, size, or orientation (Malabonga, Pasnak, Hendricks, Southard, & Lacy, 1995), although Ciancio, Rojas, McMahon, and Pasnak (2001) found that economically disadvantaged 4-year-olds enrolled in Head Start were correct on less than 44 % of such problems, and scored only 72.5 % correct after 4 months of daily learning set instruction. Understanding the relation involved is not an all or none phenomenon. For example, Gadzichowski, Pasnak, and Kidd (2013) found that children could apply it to problems composed of colored objects before they could apply it to objects differing in shape. Researchers have explored the possibility that animals could learn to solve problems that involve selecting one object that differs from others in a group of two or three. In evaluating these studies it is critical to note that the solution of a few such problems does not demonstrate that the animals are responding relationally. To be credited with understanding the relation between objects, after suitable training the animal must be able, when presented with many new problems, to select the only object of a given type from a group of objects that are identical to each other. That is, the animal must show that it can transfer this response to stimulus relationships to problems on which it has had no training. Thus, as Fields (1932) demonstrated, for animals to learn to respond in terms of a stimulus relationship, they must be presented with many concrete problems that vary widely perceptually but are all solvable in terms of that relationship (i.e., a learning set). This may produce competence in applying the relationship to new stimuli by an inductive process. Having mastered the training problems, the animals must then be tested to demonstrate that they have learned to respond to that relationship by solving on the first trial new problems that can only be solved via application of that relationship (Strong & Hedges, 1966; Thomas & Noble, 1988). The same is true for human children (Kidd et al. 2012; Kidd, Pasnak, Gadzichowski, Ferral-Like, & Gallington, 2008). Halford (1993) has pointed out that just how learning sets enable relational responding has never been determined, although Harlow (1959), Gagné (1968), and Gagné and Paradise (1961) have offered partial explanations. Because problems involving one object that differs from all others in a group require solutions based on relations between stimuli, a number of researchers have explored the possibility that animals could solve such problems. Monkeys and apes have proven to be capable of responding in terms of the oddity or "less numerous" relationship when it depends on perceiving perceptual differences between stimuli (Bernstein, 1961; Rumbaugh & McCormack, 1967; Strong & Hedges, 1966). Research involving mammals other than primates is more mixed.

There are a number of studies in which dogs (Araujo, Chan, Winka, Seymour, & Milgram, 2004; Araujo et al., 2011; Frank, Frank, Hasselbach, & Littleton, 1989; Milgram et al., 2002) or cats (Boyd & Warren, 1957) solved a few problems involving an odd or sole stimulus in a group but were not tested for transfer to new problems. Hence, these studies did not provide tests of whether the animals could respond to the oddity or "less numerous" relationship. Warren (1960) trained cats on 40 problems that had two identical objects and one different object. One cat reached a criterion of 83 % correct on these problems; the others failed after 1,920 trials. The successful cat subsequently received 24 to 48 reinforced trials on each of 30 novel problems. It made hundreds of errors on the first 10 problems (the exact number of errors was not reported) and averaged 4.5 errors on the last 20 problems. This suggests that the cat had begun to learn to respond in terms of stimulus relationships but is not adequate evidence that it had in fact learned to do so, because first trial solutions are not reported.

Strong and Hedges (1966) reported that cats and raccoons failed to learn even a few such problems to a criterion of 90 % after 4,800 training trials. However, their procedure could be considered an alternation of left and right position learning trials. The "odd" or "less numerous" stimulus never appeared in the middle of a three-stimulus triad, and animals are prone to try to solve problems via position habits, which was impossible in this case. The Strong and Hedges procedure is suboptimal for teaching the oddity or "least numerous" relationship. Even with a preferred stimulus dimension (odor), rats were not successful on transfer trials (Thomas & Noble, 1988; Bailey & Thomas, 1998). Dwarf goats produced inconsistent results; while most eventually solved the problems on which they had specific training, nearly all goats failed a transfer test involving new problems (Roitberg & Franz, 2004).

In contrast with the results of mammals other than primates, there is some evidence that birds can learn the oddity principle. Lombardi, Fachinelli, and Delius (1984); Smirnova, Lazareva, and Zorina, (2000); and Delius (1992) all conducted experiments in which birds (pigeons and hooded crows) appeared to learn the oddity principle. The evidence provided by Delius (1992) is especially convincing. Hence, it is surprising that mammals have failed.

More recently, Hille, Dehnhardt, and Mauck, (2006) provided an adequate demonstration that a sea lion could solve novel problems that had two identical stimuli and one different stimulus in a triad. All problems were comprised of two–dimensional black and white stimuli. Initially, only one problem was presented per session until the animal had met the criterion for mastery. In stage two, the sea lion was presented with all problems five times in succession, and following that, a new problem was introduced. Finally, each problem was presented to the sea lion a single time. After this extensive instruction, this semi-aquatic carnivore subsequently performed above chance on a test composed of entirely new stimuli.

What is lacking in all the experiments with other carnivores—dogs, cats, and raccoons—is a set of many training problems that could only be solved via response to the oddity or less numerous stimulus relationship, *followed by* a test that meets the criterion set forth by Strong and Hedges (1966) and emphasized by Thomas and Noble (1988). That is, solutions must be above chance on the first presentations of novel stimuli exemplifying the relationship. Hence, the present experiment was conducted with a dog, to determine whether or not this familiar and tractable carnivore could solve problems in terms of the relations between stimuli (i.e., which stimulus was odd or the only one of its kind, how difficult it would be for the animal to learn to do this, and how consistently the animal could apply what it had learned to novel problems). If a dog was successful, it would be clearer that response to stimulus relations was within the capability of these carnivores, and the range of experimental conditions under which they acquire the ability could be extended. We conducted what is sometimes called a power study, using a single subject, as did Hille et al. (2006), Rowles and Devine, (1966), and many other researchers experimenting with the abilities of animals. The basic premise is that what one member of a species can do, others of the same species may be able to do, albeit a bit better or less well. Hence, while we cannot show the upper or lower limits of dogs' performances, our participant represents a test of whether response to the oddity or least numerous relationship is within the cognitive capacity of the species.

Method

Participant

An 8-year-old male malamute–Siberian husky mix who had a history of being enthusiastic about obtaining food was brought from his home, by his owner, for each session of the experiment. His owner, over the course of more than a year, had frequently brought him to the room in which he was tested, although no apparatus had ever been present and he was entirely experimentally naive. This animal was the only one trained and tested. He was selected because he was highly motivated to obtain food and because of his familiarity with the room in which he was tested. Triana and Pasnak (1981) reported that, *if* fully mature (those 4-years-old or older) dogs tested in their homes showed fully developed object permanence; however, they also found that dogs released from their cages at an animal shelter were too excited to respond effectively to object permanence tests. Hence, on two counts, this particular dog was an ideal subject for a power study.

Apparatus and materials

A large, portable 2' × 3' tray with four food wells 3 inches from its front edge was used. The food wells were 4 inches wide, 6 inches long, and 1.5 inches deep. The food wells had 5 × 7.5 inch covers that were placed on top of the wells so that the dog could move them off the well in any direction. The apparatus also included a 5' × 6' screen that blocked the dog and a second researcher who restrained him from seeing the other researcher assembling the problems or baiting the wells. The handler, who was not in the dog's field of vision, remained silent and motionless during each trial. Additionally, the screen blocked that researcher from seeing the dog and handler. When the tray with the objects was slid under the screen to the subject, the angle of regard prevented any sight of the experimenter by the dog, or the dog by the experimenter (see Fig. 1). Training items and test items were constructed using items that can be found in the home or craft stores (see Table 1). Dog treats, dried bacon, and beef jerky were used as food reinforcers for correct answers. The type of treat was varied in order to maintain the dog's interest in the activity, saving the most attractive treat for later in the session.

Procedure

Shaping For each session, the dog was brought from his home to a room at the university, in which he had spent many hours with his owner, and was later returned to his home. The screen and sliding tray were set up in the room for each session and disassembled when the session was finished. Two researchers worked with the dog during each session; one restrained the dog by a 6-foot leash, 3 feet away from the screen, while the other researcher managed the tray. As described previously, the screen ensured that, except for the initial session described in the following paragraph, the researcher who assembled the objects on the tray could never see the dog or the other researcher who was restraining him. Likewise, the researcher restraining the dog and the dog himself could never see the researcher who assembled the problems and baited the wells. During the first session, the dog was presented with the apparatus, and the screen was removed while one researcher baited each well. The covers were placed on the wells, and the tray was presented to the dog. This was done for two reasons: first, the researchers wanted to see how the dog would remove the covers and make sure that no additional adaptations needed to be made to the apparatus. It is of particular importance that the reward be dispensed within .5 seconds of an animal's choice if possible. Additionally, although the dog was motivated by food, it was important that he understand that the wells contained food and how to get the food easily. The dog immediately showed that if he saw the wells being baited he would reliably push the covers off the wells with his nose and snatch the food from each well very quickly. In all

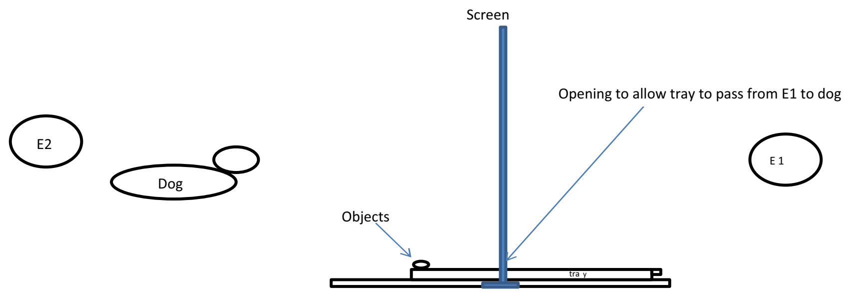

Fig. 1 Schematic of apparatus. The angle regard from the position of the dog's head and also that of the dog's handler (E2) prevented sight of the experimenter hidden behind the screen even when the screen was raised sufficiently to allow the tray and objects to pass beneath it. Likewise, the experimenter's (E1) angle of regard always prevented sight of the dog and his choices

subsequent shaping, training and testing procedures the screen was in place while *all* wells were baited and covered. In the next phase of shaping, the item that was later to be the odd one among a group of four was placed on the front edge (the edge closest to the dog) of a single cover. The other covers were bare but had the same kind of treats beneath them. When everything was in place the researcher then slid the tray under the screen toward the dog. Then the dog's handler released him. When the dog chose any of the covers that did not have the item on it, the handler pulled the dog back and told the researcher at the other end of the apparatus to withdraw the tray from the dog's reach in order to prevent the dog from obtaining food from incorrect choices. When the dog chose the cover that had an object on it, he was allowed to move the cover and retrieve the treat, whereupon the dog's handler told the other researcher to withdraw the tray. The tray was withdrawn and hidden from the view of the dog, all of the wells were baited again, and the covers were replaced. The correct item was then placed on top of a cover over a different well, according to a schedule of restricted randomization. The handler returned the dog to the starting position, and the entire process was repeated.

Training Once the dog was selecting the cover with the item on 90 % of the trials, the researcher continued to bait all the wells and cover them with the covers but added three incorrect items (i.e., items that were all the same). The position of the odd item (the least numerous in the group of four) continued to be governed by the schedule of restricted randomization. The protocol described above was followed, wherein the dog was

Table 1 Training problems

Problem	Like items	Odd item
1	3 straight stick shapes covered in tennis ball felt	1 ring shape covered in tennis ball felt
2	3 fish-shaped dog toys	1 ice-cream-shaped dog toy
3	3 wooden monkey cutouts	1 flamingo cutout
4	3 miniature cupcake liners	1 small wooden spoon
5	3 large green popsicle sticks	1 large green puff
6	3 large foam turtle shapes	1 foam heart shape
7	3 small Styrofoam balls (cut in half)	1 large Styrofoam ball (cut in half)
8	3 rubber ducks	1 rubber fire truck
9	3 large pink erasers	1 crayon
10	3 plastic bracelets	1 plastic figurine
11	3 toy cars	1 stress squeeze toy shaped like a globe
12	3 foam ovals	1 foam square
13	3 bottle caps from plastic bottles	1 multicolored cube
14	3 mini Koosh balls	1 large bouncy ball (with bottom cut flat)
15	3 small binder clips	1 glue stick
16	3 child safety scissors	1 magnifying glass
17	3 boxes of staples	1 highlighter
18	3 small paint brushes	1 small hair brush
19	3 red plastic cups	1 plastic bottle
20	3 plastic rings	1 plastic shot glass

presented with the problem, rewarded for correct selections, and prevented from being rewarded for incorrect selections. Initially, the correct item was pushed forward on the cover so it would be slightly closer than the incorrect items. As the dog began to once again select the correct item consistently, *the correct item was gradually slid back into alignment with the incorrect items.* Training was continued until the dog was 90 % correct (9/10 trials) with all items in the same alignment. When the dog had mastered the first training problem, new problems were introduced. Each session started with a "warm up," during which the dog saw the original training problem five times. Following the warm-up problems, the researchers would present the dog with a new problem. As before, all wells were baited. Each time a new problem was presented, the researchers first presented it with the correct item pushed out on its cover so as to be closer to the dog and gradually moved the item back into line with the incorrect items when the dog became regularly successful. When he reached a criterion of 90 % correct, a new problem was presented, and the procedure just described was repeated. The dog received a total of 37 sessions over the course of 2.5 months and solved 20 problems to a criterion of 90 % accuracy. Each session lasted approximately 35 minutes, during which time the dog was given 5 minutes to reacclimatize to the room. He was then presented with five warm-up problems, followed by multiple presentations of a new problem or new problems. Although the number of trials per session varied in accordance with the dog's willingness to work and the speed at which he was progressing, there were usually about 40 trials and two new problems in a session. The problems mastered are described in Table 1.

Testing During the testing phase, when the dog was presented with the problem, *all items were always positioned over the food wells in the same alignment so that none was closer to the edge of the tray than any other, and all wells were baited.* The researchers assembled 10 new problems from items that had already been used in earlier training problems. For example, if there had been three cans of Play-Doh and a matchbook used in an earlier problem, the new problem might contain three pencils and a can of Play-Doh. The item that had once been the wrong answer became the correct answer. A total of 10 novel problems created from previously used stimuli were given to the dog, and the dog was able to solve eight of them correctly on the first trial. A direct calculation of binomial probabilities indicates that $p < .002$ for a performance this accurate on problems with four alternatives. The problems used in this test are shown in Table 2.

Next, the dog was presented with 20 test problems composed of entirely new objects. The test problems were given over the course of two sessions, with 10 problems per session. The test items were different from the training problems but were the same general type (see Table 3). All items were presented over the food wells, positioned so that none was closer to the front of the tray than any other, and all wells were baited. At the beginning of each testing session the dog was once again given five trials of a practice problem he already knew. Following that the dog was presented with a total of 10 problems, with only one trial per problem. Again, the correct item was placed according to a schedule of restricted randomization. These sessions tended to be shorter in duration than the training sessions, but the problems were presented in succession without any breaks.

Results and discussion

The dog solved 14 out of the 20 test problems (70 %) correctly. Using Yate's Correction (a conservative analysis), $z = 4.25$, $p < .0001$. This performance is better than that (51 %) of the California sea lion in the study conducted by Hille et al. (2006) and surpasses the accuracy (48 %) of the most accurate goat trained and tested by Roitberg and Franz (2004), who also used problems with one right and three wrong choices. The percentage of problems solved correctly is higher than the average score (59.92 %) made by the 5-year-old human children tested by Pasnak et al. (2008) on oddity (or least numerous) problems that also had three wrong choices. Animals, much like young children, are often unpredictable and inconsistent in the display of their abilities. The problems used in the first test might be expected to be more difficult for this dog because he had to choose items that had been incorrect on his training problems and ignore items that had been correct on the first appearance of the recomposed problems. The fact that he scored so much higher than chance when faced with these inducements to make wrong choices indicates a clear understanding in terms of stimulus relations (i.e., that the correct item was the one that was odd, differing from all of the others in a group of four).

This can also be considered a relative numerosity problem. The "odd" object is per force less numerous—the sole one of its type—among those with which it is being compared. Although there is an extensive literature referring to such problems as oddity problems, the less numerous explanation is equally viable, and it is probably impossible to identify which determines the basis for response. Even if two items of one type were presented with more items of another type, the less numerous items could still be considered to be the "odd" ones. Hence, the dog can be considered to have solved either oddity problems or "least numerous" problems. That his score on the problems involving entirely novel items was lower, though still far above chance, may be due to the interest inherent in novel stimuli. Pasnak (1979) encountered a similar problem when rhesus macaques were required to apply a principle they had learned well to entirely novel stimuli. It required 26 to 78 additional training sessions before these

Table 2 Test problems constructed from familiar objects

Problem	Like items	Odd item
1	3 ring shapes covered with tennis ball felt	1 stick shape covered in tennis ball felt
2	3 crayons	1 rubber pig
3	3 wooden spoons	1 muffin liner
4	3 small hair brushes	1 bottle cap
5	3 wooden flamingo cutouts	1 rubber duck
6	3 highlighters	1 red plastic cup
7	**3 foam squares**	**1 mini Koosh ball**
8	3 magnifying glasses	1 small binder clip
9	**3 plastic shot glasses**	**1 child safety scissors**
10	3 large Styrofoam balls (cut in half)	1 small Styrofoam ball (cut in half)

Problems the subject got incorrect are shown in boldface

primates were able to apply a relational concept they had learned to novel stimuli at a high level. This may often be a problem in experiments with animals (and children) and may have contributed to the errors made by the sea lion and pygmy goats.

Table 3 Test problems constructed from novel stimuli

Problem	Like items	Odd item
1	3 wooden cube blocks	1 wooden triangle
2	3 wheels from car models	1 felt snake shape
3	3 change purses	1 plastic photo cube (without photos)
4	3 cardboard cylinders	1 cardboard box
5	3 small teddy bears	1 plastic mallet
6	3 toy hammers	1 toy drum
7	**3 large flat seashells**	**1 large smooth pebble**
8	3 mini rolling pins	1 measuring cup
9	3 pencils	1 pliers
10	**3 wooden sun cutouts**	**1 wooden ice-cream cut out**
11	3 plastic star-shaped bath toys	1 doughnut dog toy
12	3 very large washers	1 large screw
13	**3 giant paperclips**	**1 dry-erase board eraser**
14	**3 Tupperware lids**	**1 wooden clock**
15	3 mini piggy banks (pig shape)	1 plastic brain wind-up toy
16	**3 Styrofoam cones**	**1 finger puppet**
17	3 felt letter X	1 felt ring
18	3 large plastic rings	1 plastic yo-yo
19	**3 rubber shoe0-shaped dog toys**	**1 rubber chicken-shaped dog toy**
20	3 stuffed bees	1 pinecone

Problems 10–20 were administered in a second testing session. Problems the subject got incorrect are shown in boldface

It is noteworthy that this dog required only 37 training sessions to perform at a relatively high level on the problems he was taught, despite having to also learn how to obtain food from the apparatus, that the stimuli governed whether he could in fact obtain food, and that he had to observe and compare them. This was much less than the 92 sessions required by the sea lion but about the same as the 36 sessions offered to the goats, all but one of whom failed a transfer test that used new stimuli. It appears that that the stimulus relation was not difficult for him to grasp. This may reflect a predisposition: the wild ancestors of domestic dogs must often choose the only animal that differs from others in a group—one with a different gait or posture—as a matter of survival. Cats, in contrast, are ambush hunters, and sea lions depend primarily on speed and agility in obtaining food. There are also differences in the response topography of different species. It is natural for a dog to push with his nose; cats, however, prefer to swipe at objects with their paw and may require an apparatus that accommodates this tendency. The sea lion trained by Hille et al. (2006) had to raise the stimulus plate with its nose, which might be less natural than pushing or seizing it. These differences make fair comparisons of the learning rates of different species difficult. The training procedure used the present experiment, where the odd (or less numerous) stimulus was initially closer to the dog and only retreated gradually until it was perfectly aligned with the other stimuli probably made the problems easier to learn. The goats and sea lion had to learn to solve the problems without gradual approximations to the discriminations desired. However, there are so many differences in both procedures and stimuli that may have a bearing on the efficiency with which the different animals progressed, that comparisons between species are not presently realistic. For example, the goats of Roitberg and Franz (2004) had to retreat from the stimuli in order to obtain food after making a correct choice; this may have impeded their learning. We note that problems in which stimuli differ in many dimensions, as was the case for this dog, are presumably easier to learn than problems in which stimuli differ in only one dimension, as was the case for the sea lion and pigeons (Delius, 1992; Hille et al., 2006). Changes in environment may interfere with learning when animals are brought to a new environment for testing (Strong, 1965; Triana & Pasnak, 1981). This dog was familiar with and relatively relaxed in the testing environment, and was very motivated to get dog treats. Hence, his performance may have been especially good. In any event, it is clear from the present research that response in terms of stimulus relations is within a dog's capabilities, even when reversing a previously correct choice is required, as in the first test offered in this experiment. However, there is no evidence in this experiment that the dog could apply the relation he had learned regardless of the dimension of difference, a criterion advanced by Penn, Holyoak, and Povinelli (2008) in discussing the differences between abstractions by humans and animals. Penn et al. argued that to truly understand an abstract principle, one must be able to apply it to any stimulus dimension, and that this was an important difference between humans and animals. This is a limitation of the study described in this paper; the subject's ability to respond to all potential dimensions was not tested, and, hence, his ability to completely respond to an oddity or least numerous relation does not meet the definition of Penn et al. However, humans do not learn the oddity or less numerous relationship in a dimension-free manner. Children may solve such problems presented in one dimension, but not another (Gadzichowski et al., 2013). Thus, the relations between stimuli may be understood in one dimension but not others. Gadzichowski et al. found that preschoolers, who develop solutions of such problems without instruction, were not at all independent of the dimension of stimulus difference. Performance varied significantly and substantially according to whether the relevant dimension was color, size, or form. Hence, being able to select the odd or least numerous stimulus when stimuli differ in one dimension does *not* imply, for humans or animals, that one has the capability of applying it to other stimulus dimensions. Indeed, Kidd et al. (2012) found that children who were taught to apply the oddity or least numerous relationship to shapes needed substantial additional instruction to apply it to size, and still more to apply it to the dimension of orientation.

There is also no evidence in the present experiment that the dog could apply the principle of stimulus relations he had learned to make higher order inferences, another ability that Penn et al. (2008) argued distinguished human and animal minds. There is, in fact, no reason to think that this dog had higher order abilities, and he clearly did not understand and was not responding to the oddity or least numerous stimulus relation at the outset of the experiment. What we do have here is the first demonstration that, after suitable shaping and training, a dog can discriminate the odd or least numerous object from among a set of perceptually different objects the first time he sees the set, if the stimuli are objects that differ in multiple dimensions.

References

Araujo, J. A., Chan, A. D. F., Winka, L. L., Seymour, P. A., & Milgram, N. W. (2004). Dose-specific effects of scopolamine on canine cognition: Impairment of visuospatial memory, but not visuospatial discrimination. *Psychopharmacology, 175,* 92–98.

Araujo, J. A., Greig, N. H., Ingram, D. K., Sandin, J., de Rivera, C., & Milgram, N. W. (2011). Cholinesterase inhibitors improve both memory and complex learning in aged beagle dogs. *Journal of Alzheimer's Disease, 26,* 143–155.

Bailey, A. M., & Thomas, R. K. (1998). An investigation of oddity concept learning by rats. *Psychological Record, 48,* 333–344.

Bernstein, I. S. (1961). The utilization of visual cues in dimension-abstracted oddity by primates. *Journal of Comparative and Physiological Psychology, 54,* 243–247.

Boyd, B. O., & Warren, J. M. (1957). Solution of oddity problems by cats. *Journal of Comparative and Physiological Psychology, 50,* 258–260.

Ciancio, D., Rojas, A. C., McMahon, K., & Pasnak, R. (2001). Teaching oddity and insertion to Head Start children: An economical cognitive intervention. *Journal of Applied Developmental Psychology, 22,* 603–621.

Delius, J. D. (1992). Categorical discrimination of objects and pictures by pigeons. *Animal Learning and Behavior, 20,* 301–311.

Fields, P. E. (1932). The development of the concept of triangularity by the white rat. *Comparative Psychology Monographs, 9,* 1–70.

Frank, H., Frank, M. G., Hasslebach, L. M., & Littleton, D. M. (1989). Motivation and insight in wolf (*Canis lupis*) and Alaskan malamute (*Canis familiaris*): Visual discrimination learning. *Bulletin of the Psychonomic Society, 27,* 455–458.

Gadzichowski, K. M., Pasnak, R., & Kidd, J. K. (2013). What's odd about that? Exploring preschoolers' ability to apply the oddity principle to stimuli differing in colour, size, or form. *European Journal of Developmental Psychology, 10,* 739–751.

Gagné, R. M. (1968). Contributions of learning to human development. *Psychological Review, 75,* 177–191.

Gagné, R. M., & Paradise, N. E. (1961). Abilities and learning sets in knowledge acquisition. *Psychological Monographs, 75*, (Whole number 518).

Halford, G. S. (1993). *Children's understanding: The development of mental modes*. Hillsdale: Erlbaum.

Harlow, H. (1959). Learning set and error factor theory. In S. Koch (Ed.), *Psychology: A study of a science* (Vol. 2). New York: McGraw-Hill.

Herrnstein, R. J., Loveland, D. H., & Cable, C. (1976). Natural concepts in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes, 2,* 285–302.

Hille, P., Dehnhardt, G., & Mauck, B. (2006). An analysis of visual oddity concept learning in a California sea lion (*Zalophus californianus*). *Learning & Behavior, 34,* 144–153.

Kidd, J. K., Curby, T. W., Boyer, C. E., Gadzichowski, K. M., Gallington, D. A., Machado, J. A., & Pasnak, R. (2012). Benefits of interventions focused on oddity and seriation, literacy, or numeracy. *Early Education and Development, 23,* 900–918.

Kidd, J. K., Pasnak, R., Gadzichowski, M., Ferral-Like, M., & Gallington, D. (2008). Enhancing kindergartners' mathematics achievement by promoting early abstract thought. *Journal of Advanced Academics, 19,* 164–200.

Lombardi, C. M., Fachinelli, C. C., & Delius, J. D. (1984). Oddity of visual pattern conceptualized by pigeons. *Animal Learning and Behavior, 12,* 2–6.

Malabonga, V., Pasnak, R., Hendricks, C., Southard, M., & Lacy, S. (1995). Cognitive gains for kindergartners instructed in seriation and classification. *Child Study Journal, 25,* 79–96.

Milgram, N. W., Zicker, S. C., Head, E., Muggenburg, B. A., Murphey, H., Ikeda-Douglas, C. J., & Cottman, C. W. (2002). Dietary enrichment counteracts age-associated cognitive dysfunction in canines. *Neurobiology of Aging, 23,* 737–745.

Pasnak, R. (1979) Acquisition of Prerequisits to Conservation by macaques. *Journal of Experimental Psychology: Animal Behavior Processes, 5*(2), 194–210

Pasnak, R., Kidd, J. K., Gadzichowski, K. M., Gallington, D., Saracina, R. P., & Addison, K. (2008). Can Emphasizing Cognitive Development Improve Academic Achievement? *Educational Research, 50*, 261–276

Penn, D. C., Holyoak, K. J., & Povinelli, D. J. (2008). Darwin's mistake: Explaining the discontinuity between human and nonhuman minds. *Behavior and Brain Sciences, 31,* 109–178.

Roit+berg, E., & Franz, H. (2004). Oddity learning by African dwarf goats (*Capra hircus*). *Animal Cognition, 7,* 61–67.

Rowles, F. H., & Devine, J. V. (1966). Chimpanzee performance on a problem involving the middleness concept. *Animal Behavior, 14,* 159–162.

Rumbaugh, D. M., & McCormack, D. (1967). The learning skills of primates: A comparative study of apes and monkeys. In D. Stark, R. Schneider, & H. J. Kuhn (Eds.), *Progress in Primatology* (pp. 289–306). Stuttgart: Gustav Fischer.

Smirnova, A. A., Lazareva, O. F., & Zorina, Z. A. (2000). Use of number by crows: Investigation by matching and oddity learning. *Journal of the Experimental Analysis of Behavior, 73,* 163–176.

Strong, P. N. (1965). Learning and transfer of oddity as a function of apparatus and trials per problem. *Psychonomic Science, 3,* 19–20.

Strong, P. N., & Hedges, M. (1966). Comparative studies in simple oddity learning. *Psychonomic Science, 5,* 13–14.

Thomas, R. K. (1980). Evolution of intelligence: An approach to its assessment. *Brain, Behavior and Evolution, 17,* 454–472.

Thomas, R. K., & Noble, L. N. M. (1988). Visual and olfactory oddity learning in rats: What evidence is necessary to show conceptual behavior? *Animal Learning and Behavior, 16,* 157–163.

Triana, E., & Pasnak, R. (1981). Object permanence in cats and dogs. *Animal Learning and Behavior, 9,* 135–139.

Warren, J. M. (1960). Oddity learning set in a cat. *Journal of Comparative and Physiological Psychology, 53,* 433–434.