Anim Cogn (2004) 7 : 61–67
DOI 10.1007/s10071-003-0190-y

ORIGINAL ARTICLE

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Oddity learning by African dwarf goats (*Capra hircus*)

Received: 11 January 2003 / Revised: 22 July 2003 / Accepted: 1 August 2003 / Published online: 10 September 2003

Abstract Seventeen African dwarf goats (adult females) were trained on oddity tasks using an automated learning device. One odd stimulus and three identical nonodd stimuli were presented on a screen divided into four sectors; the sector for the odd stimulus was varied pseudorandomly. Responses to the odd stimulus were deemed to be correct and were reinforced with food. In phase 1, the goats were trained on eight stimulus configurations. From trial to trial the odd discriminandum was either a + symbol or the letter S, and the nonodd discriminandum was the symbol not used as the odd one. In phase 2, the animals were similarly trained using an unfilled triangle or a filled (i.e., solid black) circle. In phase 3, three new discriminanda were used, an unfilled, small circle with radiating lines, an unfilled heart-shaped symbol, and an unfilled oval; which of the three discriminanda was odd and nonodd was varied from trial to trial. Following these training phases, a transfer test was given, which involved 24 new discriminanda sets. These were presented twice for a total of 48 transfer test trials. Results early in training showed approximately 25% correct, which might be expected by chance in a four-choice task. After 500–2,000 trials, results improved to approximately 40–44% correct. The best-performing subject reached 60–80% correct during training. On the transfer test, this subject had 47.9% correct and that significantly exceeded 25% expected by chance. This finding suggests that some exceptional individuals of African dwarf goats are capable of learning the oddity concept.

Keywords Automated learning device · Concept formation · Goats · Oddity problem · Visual discrimination learning

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Introduction

Operant conditioning studies of concept formation by nonhuman animals have been limited to relatively few species, most of which appear to have been chosen for laboratory convenience (e.g., rats, pigeons) or because they are of particular interest in relation to the evolution of human mind or intelligence (e.g., apes and monkeys). While there has also been some research with cats (Boyd and Warren 1957; Strong, Hedges 1966), racoons (Strong and Hedges 1966), a civet cat (Rensch and Dücker 1959), corvid birds (Friede 1972; Wilson et al. 1985; Smirnova et al. 2000), a parrot (Pepperberg 1987), fish (Zerbolio and Royalty 1983) and honeybees (Giurfa et al. 2001), many species, including farm animals and ruminant mammals in general, have been largely neglected. Increasing the number of animal taxa whose abilities have been examined on such foundational tasks as the oddity concept learning tasks enriches general knowledge of cognitive abilities from a comparative perspective (Wasserman 1993; Lock and Colombo 1996; Thompson 1995; Thomas 1996; Czeschlik 1998). Additionally, the cognitive ability of farm animals is of practical interest, for example, in the development of automated equipment for animal upkeep.

This paper presents some results of investigations of learning and cognitive abilities of African dwarf goats (*Capra hircus* L.) using an automated device for operant conditioning (Franz and Reichert 1999; Franz et al. 2002). Goats have been trained successfully to discriminate visual stimuli (Soltysik and Baldwin 1972; Baldwin 1979; Franz and Reichert 1999). It is now important to test their ability for abstract concept formation, and the long-used oddity task (e.g., Robinson 1933). The oddity task has been adapted to test for animals' abilities to use relative class concepts (Moon and Harlow 1955; Thomas, 1980) and should be easily adaptable to testing with goats.

The oddity concept is an important example of relative class concepts in the hierarchy of intellectual abilities (Thomas 1980). With the oddity procedure, the odd stimulus and two or more identical or nonodd stimuli are presented simultaneously. Oddity tasks have been widely used to study the comparative learning abilities of animals (see Thomas and Noble 1988; Bailey and Thomas 1998 and the references they cited). Thomas and his colleagues have argued that there is no unambiguous evidence for use of the oddity concept by nonprimate animals, because the studies have confounded the possibility of specific stimulus learning as opposed to learning the oddity concept. Thomas and colleagues do not conclude, however, that nonprimate animals cannot learn the oddity concept, only that the studies have been methodologically inconclusive.

The aim of the present investigation was to test whether dwarf goats might show use of the oddity concept. To avoid specific stimulus learning interpretations, the present study based its evidence for the conceptual use of oddity on the performances seen on the first trials with new discriminanda (or by allowing individual discriminanda to serve as both odd and nonodd stimuli, thereby, preventing a given discriminandum from being exclusively associated with oddity). Additionally, the use of an operant conditioning device (Franz and Reichert 1999; Franz et al. 2002) enabled the concurrent training of 10–20 animals, thereby increasing the opportunity to identify possibly exceptional individuals with respect to the use of the oddity concept.

Methods

Subjects

Seventeen adult female goats from our Institute's breed were used for the oddity learning experiments. The subjects were trained and housed as a group in a large indoor pen. All subjects were in healthy condition throughout the experiments. All procedures involving animal handling and treatment were approved by the Committee for Animal Use and Care of the Agricultural Department of Mecklenburg–West Pomerania, Germany. At the time of oddity training the goats ranged in age from 1.5 to 4 years.

Subjects' prior training history

When they were 4–6 months old, most had experience training for object discrimination using simple geometric figures and Roman letters (Franz et al. 2002). Some of the subjects were subsequently trained for relative numerousness judgments involving arrays of from one to six black dots. About 5 months before the goats were trained on the oddity tasks, they had experienced a series of 20 oddity discrimination tasks in which an odd stimulus was presented concurrently with three identical, nonodd stimuli. Since, within each task the same four stimuli were presented numerous times, with only the position of the odd stimulus varying among problems, it was possible, even likely, that the animals would learn and remember the specific features of the odd stimulus rather than its relative property of being the "odd" one. Such oddity tasks have been referred to as "one-odd problems." These have been deemed to be inconclusive with respect to the oddity concept, because specific property learning is confounded with oddity learning (see Noble and Thomas 1970). Training on each one-odd problem ranged from 1 to 6 days for a total duration of 50 days of such pretraining. The results of the pretraining provided some evidence for generalization of absolute properties of the odd stimulus, but not for concept formation.

Apparatus

Training and testing procedures and data collection were performed using an automated learning device, known as a field monitor – a general purpose computer system for operant conditioning experiments (Franz and Reichert 1999; Franz et al. 2002). The learning device consisted of a 17'' computer monitor (TFT display). Superimposed on the monitor's screen was clear acrylic glass divided into four sectors. On each sector, one of the four visual stimuli was presented. Each sector contained a switch located close to the corresponding visual stimulus. Pressing a switch manifested an animal´s choice. If the correct stimulus was chosen, the automated learning device delivered a portion of granulated food concentrate (reinforcer) into a bowl which was centrally positioned and located approximately 35 cm in front of the screen. This distance required the animals to retreat after a correct choice to eat the reinforcer, and then move back to the screen for the next trial.

Animals in the experimental group had free access to the device throughout the 24-hour day. The animals wore transponders for individual recognition by an animal identification system (Urban, Germany). To prevent the animals from disturbing each other while visiting the device and to make sure that they could be registered individually, each field monitor was arranged in a compartment box, measurements of which made the entry of more than one animal nearly impossible (see Franz and Reichert 1999, and Franz et al. 2002, for further details about this learning device).

Learning procedure

Our experiments used the four-choice procedure. That is, on each presentation, one odd stimulus and three identical nonodd stimuli were presented simultaneously. The animals were rewarded for each choice of the odd stimulus by a portion of food concentrate.

After each actuation of a switch, stimuli ceased to be visible on the screen. Further actuations within this period of blank screen were registered but did not result in delivery of a reinforcer. The duration of blank screen which defined the intertrial interval (ITI) was 17 s following an incorrect choice and 20 s following a correct choice; the correct choice ITI also included the time required to deliver the reinforcer. Following the ITI the presentation of the next array of stimuli (see following description) occurred regardless of whether the choice had been correct or not.

The position of the odd stimulus was varied pseudo-randomly in a sequence of 24 consecutive presentations (arrays of stimuli), cyclically repeated for each individual subject throughout an experiment. In phase 1 of training, the discriminanda were a + symbol and the letter S. Sizes of the stimuli were 60×55 mm and 60×45 mm, respectively. On a given trial, either the + or the S might be the odd stimulus and the symbol not used as the odd stimulus was used for the nonodd stimuli. Phase 2 of training was similar to phase 1 except that the discriminanda were a solid black circle and an unfilled triangle (i.e., line drawing). Sizes of the stimuli were 40×40 mm. In phase 3, three new discriminada were used, a small, unfilled circle with radiating lines, an unfilled heart symbol, and an unfilled oval (sizes of the stimuli were from 50×50 to 40×60 mm) and as before, on a given trial either of the three might be odd while one of the other figures served as the nonodd stimulus.

To overcome position preferences, which frequently occur with animals performing complicated learning tasks, a correction program (Franz 2001; Franz et al. 2002) was employed. Briefly, if in a series of 14 consecutive trials with a particular animal 9 responses were made in either the upper, lower, left or right halves, this animal subsequently received a modified series of problems in which the odd stimulus appeared only in the opposite half of the screen. As soon as a subject exhibited 40% correct choices in a series of 14 trials, the standard sequence of problems, encompassing all dispositions of the stimuli, was reinstituted.

Training phases 1, 2, and 3 lasted 21, 5, and 10 days, respectively. Duration of a particular training phase was generally determined by acquisition curves of a few best learners: when they appeared to be near their asymptotes, that phase of training was replaced with the next one.

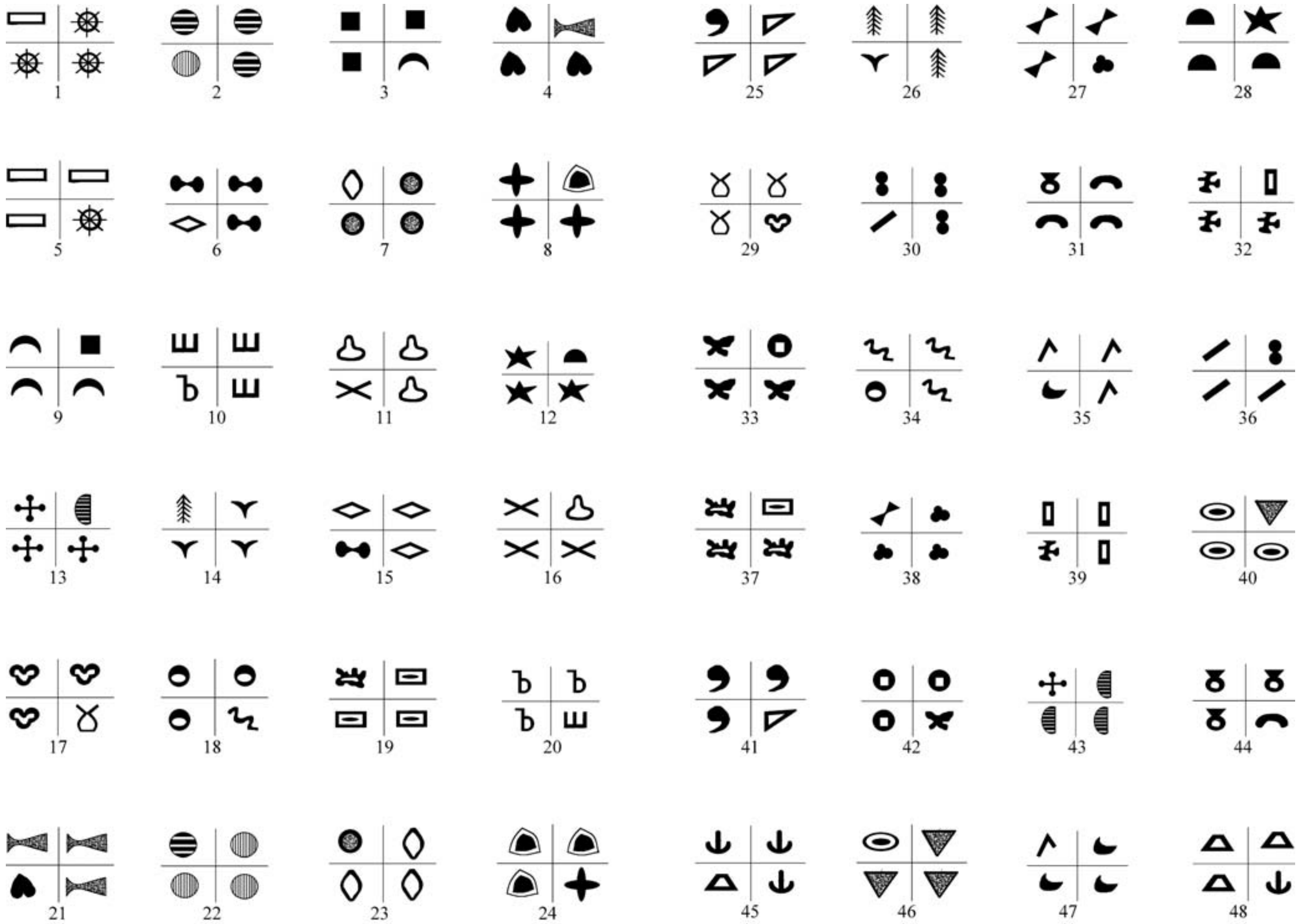

Fig. 1 Problems of the transfer test (numbers of problems correspond to the order of presentation). See text for explanations

Transfer test

A transfer test with 48 problems involving 24 new discriminanda (Fig. 1) was used to confirm acquisition of the abstract oddity rule. Each set of discriminanda was presented twice. Each geometric figure occurred as the odd stimulus only once in the series of 48 test problems. The position of the odd stimulus was varied pseudo-randomly throughout the series of 48 test problems. The other procedures of the transfer test were like those in phases 1–3 of training, except that the program to correct position bias was not used. For each subject, only the first trial for each problem was considered for calculation of test performance.

Each actuation of a switch triggered data collection as follows: (1) individual number of the animal; (2) time; (3) position of the chosen switch (i.e., screen sector); (4) positions of the odd stimulus; (5) current state of the screen (active or blank); (6) if active, the name of the bitmap containing the currently offered disposition of stimuli; and (7) whether the currently involved subroutine was the standard or the control for position preferences.

Data analysis

As the subjects had free access to the learning device throughout the experiment, daily trials varied both between subjects and across experimental days. Taking into account that in most cases the number of daily trials per subject was within a range of 50–150, the percent of correct choices for an animal in a day was used to assess training progress. In calculating the percentage of correct choices, the responses made during the ITI (blank screen) were excluded from the analysis. However, the trials deemed to have occurred in conjunction with a side bias were included. Although it is debatable (see Discussion), we accepted chance performance as being 25% correct, because it should result from a random selection of one of the four sectors of the screen.

Results

Performances of the 17 goats during the three training phases are summarized in Fig. 2. For goat 508, the best performing subject, the acquisition curve is included separately from the group data in Fig. 2. As may be seen, she reached a level of 70–75% in 10–13 days during training phase 1, and performed consistently about 50% correct in the latter days of training phases 2 and 3. None of the other 16 subjects managed to consistently exceed a level of 50% correct. Still, some statistically better-than-chance performances occurred in this group: correlation between the daily performance and the time was positive for 15 of the 16 subjects (sign test, $P < 0.001$) in training 1 and training 3. For most of subjects, the total number of trials during the training phase amounted to 1,500–2,500.

Fig. 2 Performance of 17 adult female goats by oddity learning in three consecutive trainings. The individual data are summarized in boxplots including the median (*bold horizontal line*), the 25th and 75th percentiles (*box*), range without outliers (*vertical line*), and outliers (observations located more than two interquartile ranges above or below the median) indicated as *open circles*. For each training day, only subjects that had made at least ten trials were considered. The individual acquisition curve of subject 508 (outstanding learner) is also indicated

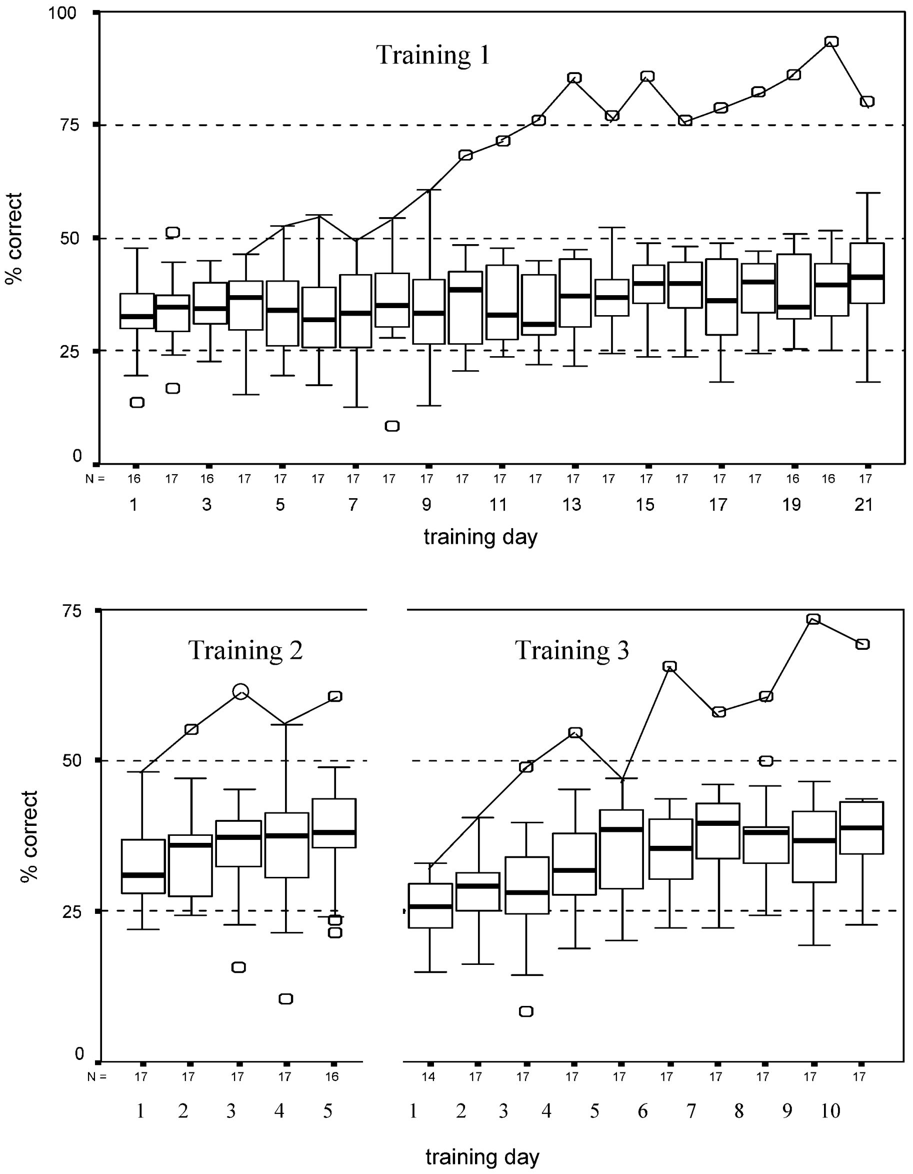

Table 1 Two-way repeated measures ANOVAs with learning performance as the dependent variable, training day as the within-subject factor and subgroup as the among-subject factor

Learning procedure	Source	*df*	*F*	*P*
Training 1	Subgroup	1	27.98	<0.001
	Training day	20	11.17	0.005
	Subgroup × training day	20	6.62	0.02
Training 2	Subgroup	1	16.37	0.001
	Training day	4	1.47	0.245
	Subgroup × training day	4	0.64	0.44
Training 3	Subgroup	1	27.01	<0.001
	Training day	9	9.51	0.009
	Subgroup × training day	9	3.46	0.09

To assess whether the training performance of goat 508 deviated significantly from that of the other 16 subjects, we performed a two-way repeated measures analysis of variance (ANOVA), training day × subgroup. Goat 508 was considered as subgroup 1 and the rest of the group as subgroup 2. For all three training procedures the effect of subgroup was highly significant (Table 1). For training procedure 1, the ANOVAs also revealed a significant subgroup × training day interaction (Table 1).

Table 2 First trial performances of the 17 adult female goats in the transfer test for oddity discrimination (48 problems with unfamiliar visual patterns). For comparison, training performances during the last 2 training days are also presented. Performance values which significantly exceeded the chance level of 25% are indicated (see notes)

Subject no.	% correct choice and the number of trials (in parenthesis)	
	Last 2 days of training	Test (first trials)
147	36.05 (147)*	18.75 (48)
174	22.86 (105)	29.17 (48)
211	38.80 (183)***	33.33 (48)
301	33.33 (78)	22.92 (48)
351	43.59 (78)***	31.25 (48)
468	43.64 (110)***	37.50 (48)
508	69.33 (163)***	47.92 (48)***
513	34.51 (142)*	35.42 (48)
514	34.62 (104)	31.25 (48)
547	43.70 (135)***	20.83 (48)
557	43.14 (51)*	20.83 (48)
579	37.35 (83)*	25.00 (48)
581	42.86 (77)**	25.00 (48)
606	43.24 (74)**	20.83 (48)
608	42.86 (56)*	22.92 (48)
633	36.36 (154)**	35.42 (48)
652	33.33 (102)	25.00 (48)

*$P < 0.05$
**$P < 0.01$
***$P < 0.001$

Transfer test

On the transfer test with 48 combinations of 24 new visual stimuli, the first trial performances of 16 out of the 17 studied animals (subgroup 2) varied between 18.75 and 37.50% and did not exceed the chance level of 25% significantly (Table 2). The 17th subject, goat 508, exhibited a performance of 47.9% ($n = 48$), which significantly exceeded 25% expected by chance (binomial approximation test, $P < 0.001$). Even after a Bonferroni correction, this result remains significant: $\alpha' = \alpha / n = 0.05/17 \approx 0.003 > 0.001$. The first trial performance of goat 508 for problems 1–24 (33.3%, $n = 24$) was significantly ($P < 0.05$) lower than that for problems 25–48 (62.5%, $n = 24$). We also compared the first trial performance of goat 508 for the following two groups of problems: group 1 included the problems in which a given pair of stimuli appeared for the first time (Fig. 1, *1*, *2*, *3*, *4*, *6*, etc.), and group 2 included the problems in which a given pair of stimuli appeared the second time but with an alteration of the quality and (in most cases) the position of the odd figures (Fig. 1, *5*, *22*, *9*, *21*, *15*, etc.). The corresponding values for the two groups of problems were very similar to one another, amounting 45.8% and 50.0% ($n = 24$ for both groups).

Additionally, goat 508 had a run of 10 correct in 12 successive first trials ($P < 0.01$; see Table 11 in Bogartz 1965 for relevant statistics of run analysis) associated with problems 28–39 and a nearly perfect run of 8 *incorrect* responses in 9 successive first trials associated with problems 8–16. Interestingly, this goat exhibited some position bias when responding to novel stimuli. It chose field 4 (the lower right sector of the screen) 10 times in 11 successive first trials ($P < 0.01$; see Table 11 in Bogartz 1965) associated with problems 8–19. However, in 18 successive first trials associated with problems 30–47 she did not actuate field 4 at all. The performance of goat 508 by the 2nd, 3rd, 4th, and 5th trials on the 48 test problems amounted to 41.7%, 53.1%, 36.5%, 40.6%, respectively. None of these values differed significantly from her first trial performance of 47.9%.

Discussion

The low training performances seen with all but one goat in training phases 1–3 can hardly be ascribed to inability to make the necessary visual discriminations; the same subjects trained for simple visual discrimination in previous experiments involving similar visual stimuli attained 70–90% correct by the 4th–7th training day or 200–400 trials (Franz et al. 2002). Along with a possible lack of capability to form the oddity concept (i.e., reliably associate the odd discriminanda with reinforcement) and as yet unrecognized shortcomings of our training procedures, one identifiable factor may have contributed to the low performances of most of the goats. Our automated device allowed a subject to make an almost unlimited number of responses during quite a short time and, thus, enabled each goat to obtain the reinforcers via persistent responding; therefore, its motivation to respond correctly each time might be lower here as compared with the traditional design where the number of trials and, therefore, responses is limited.

Following Robinson's (1933) use of the two-odd task (inconclusive for the oddity concept), several modifications for the purpose of providing evidence for oddity concept use were made (Meyer and Harlow 1949; Strong and Hedges 1966; Thomas and Boyd 1973 and references therein). The version used in our training is related to the standard oddity procedure in which the shifts of position and quality of the odd stimulus form a randomized sequence (Moon and Harlow 1955). The only substantial deviation here is that our stimuli arrays had three rather than two nonodd stimuli. Using a larger number of negative stimuli was expected to facilitate discrimination learning (Williams 1967; see also Franz and Roitberg 2001).

To oppose use of a strategy of memorizing particular stimulus configurations (an item-specific strategy) instead of learning a general rule, we did not employ any other simplifications of the standard oddity procedure. However, further simplifications at the pretraining phase as well as employing a larger total number of stimuli might be used for the future experiments to facilitate initial acquisition (Strong and Hedges 1966; Friede 1972; Thomas and Boyd 1973).

It has been argued that stringent evidence for oddity concept formation is available thus far only for primates

(Harlow 1958; Strong and Hedges 1966; Thomas and Boyd 1973; Bailey and Thomas 1998) and – with some reservations – for corvid birds.[1] (Friede 1972). Training of cats and racoons was unsuccessful after as many as 4,800 trials (Strong and Hedges 1966). Rats were also unable to acquire the oddity concept (i.e., learning to choose the odd stimulus as a reliable way to obtain reinforcers) either in visual or in olfactory modalities (Thomas and Noble 1988). However, a recent investigation of oddity learning by rats provides some positive evidence (Bailey and Thomas 1998), which is discussed below. Other reported evidence (e.g., Wodinsky and Bitterman 1953; Pastore 1954; Boyd and Warren 1957) is less convincing due to the possibility of learning specific stimulus configurations or other confounding variables (Thomas and Noble 1988; Thomas 1996; Bailey and Thomas 1998).

In the present study only one of the 17 goats performed significantly above chance on the first trials of a transfer test with new visual patterns. This subject (goat 508) distinctly outperformed the other studied goats also in the training phase, reaching a training performance of 70–75%, and its first trial performance on new problems was well above chance (Table 2). Although the first trial performance is regarded as a quite reliable indicator of concept formation (Thomas and Noble 1988, etc.) some possible objections to our evidence should be considered.

One concern is an apparent decrease of performance in the transfer test compared to that of the last days of training (Table 1). However such a decrease might be related to behavioral disruption induced by the novelty of the new stimuli. For example, D'Amato et al. (1985) suggested that some perceptual learning about the new stimuli may be required before animals can deal with them optimally. The fact that the goat 508's trial 1 performance on the first 24 trials was lower than that for the 24 subsequent trials might argue for such a behavioral disruption. However, the lack of increase in performance by trials 2–5 as compared to the trial 1 performance does not support this explanation. A test performance which is better than chance, but lower than the training performance might also mean that the subject used a complex strategy combining concept use with an item-specific strategy (Wright et al. 1984) and/or with other nonconceptual strategies. The latter explanation seems plausible for the case considered. Even some temporal position preference was involved in the choice strategy of goat 508 by its first trials on the test problems.

The alternative, "solely nonconceptual" explanation would assume that the pronounced acquisition in performance for each training task occurred by simply memorizing the individual stimuli configurations. The better-than-chance performance on test trials would then be attributed to the subsequent generalizing of common features of the previous stimuli to the new ones. Although this scenario cannot be excluded completely, because we do not know what specific features the goat may have detected in those stimuli, it seems improbable, as the differences between the training stimuli (see description in Methods) and the stimuli used in the transfer test (Fig. 1) were substantial.

Perhaps, the most serious challenge to whether the present results show use of the oddity concept is the present use of 25% as the value for chance. Some have argued (see Thomas and Frost 1983 and Bailey and Thomas 1998 for related discussion) that chance in an oddity experiment should be considered to be 50%, because the choice between the odd and the nonodd discriminanda might be made merely on the basis that the animal discriminates between the physical properties of the odd and the physical properties of identical nonodd stimuli; that is, the animal need not perceive the oddness of the odd stimulus and may choose the odd stimulus only by chance in discriminating between it and the nonodd stimuli. Thus, there are two compelling logical arguments, one for chance being 25% in a four-choice oddity experiment and one for chance being 50% in an oddity task no matter how many nonodd stimuli are used on a given trial. We elected the more liberal 25% value for chance here in part because the starting performance by the goats on the training tasks was consistently close to 25%. Additionally, until the question of what is the most appropriate way to specify chance in oddity experiments has been resolved, we felt it was justified to use the more liberal value in the interest of suggesting the possibility that some goats (such as goat 508) may be capable of the oddity concept.

Bailey and Thomas (1998) studied oddity learning by rats in the frame of the traditional three-choice paradigm, using olfactory stimuli. For the entire block of 60 test problems, the first trial performance of the four studied rats did not exceed chance. However one rat had two significant near-perfect runs of correct responses within the first half of the block (Bailey and Thomas 1998). Assuming that "oddity per se is a highly salient perceptual cue," Bailey and Thomas (1998, p 340) suggested that "this rat did not *learn* the oddity cue but that he perceived it and almost immediately associated it with reinforcers."

However, the studied goats appeared to have only a slight (if any) pretraining preference for the odd stimulus. Even by the last training (training 3), the starting performance amounted on an average to 25.5% correct for the whole group and 33.0% correct for goat 508. Furthermore, rapid learning set formation, as seen in some of the rat studies (Thomas and Noble 1988; Bailey and Thomas 1998) and attributed to the perceptual salience of the odd stimulus (Bailey and Thomas 1998), was not the case for goat 508. Her trial 1 performance did not differ from her performance for trials 2–5. At the same time, goat 508's trial 1 performance included a near-perfect run of correct choices (problems 28–39) and a nearly perfect run of incorrect choices (problems 8–16). This might indicate that

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[1] For the oddity-from-sample task such evidence was obtained for pigeons (Lombardi et al. 1984), corvid birds (Smirnova et al. 2000) and even honey-bees (Giurfa et al. 2001). Pigeons were also found to solve the same–different discrimination task in which two response keys were associated with the two alternative relations rather than the two presented stimuli (Wright et al. 1984; Wasserman et al. 1995). However, these procedures do not seem to be directly comparable to the oddity task.

by the onset of the test problems a temporary preference for the odd stimulus as suggested by the significant near-perfect run had not been well associated with reinforcement and the run of incorrect responses might represent the goat's attempt to investigate what the reliable reinforcement contingencies might be. In any case, the significant runs, both correct and incorrect, suggest that *something* is affecting the goat's performances in relation to the oddity stimulus.

In summary, the present investigation of oddity concept learning by 17 adult female goats suggests that some species of nonprimate mammals, namely, African dwarf goats, may include exceptional individuals (e.g., goat 508) whose performances indicate some use (or misuse) of oddity relationships. Obviously, further research is necessary to obtain more definitive conclusions.

Acknowledgements The authors greatly appreciate the expert technical assistance of K. Siebert and D. Sehland and their untiring care for the animals and the training technique. We are thankful to O. Lazareva for valuable methodological advice and to G. Manteuffel and B. Puppe for their critical comments on an earlier version of the manuscript. Our special thanks go to R.K. Thomas for his assistance with the manuscript. Critical comments of the two anonymous reviewers are also appreciated. This research was supported by the Deutsche Forschungsgemeinschaft (grant F 1481/1–1 to H. Franz).

References

Bailey AM, Thomas RK (1998) An investigation of oddity concept learning by rats. Psychol Rec 48:333–344

Baldwin BA (1979) Operant studies on shape discrimination in goats. Physiol Behav 23: 455–459

Bogartz RS (1965) The criterion method: some analyses and remarks. Psychol Bull 64:1–14

Boyd OB, Warren JM (1957) Solution of oddity problems by cats. J Comp Psychol 50:258–260

Czeschlik T (1998) Animal cognition – the phylogeny and ontogeny of cognitive abilities. Anim Cogn 1:1–2

D´Amato MR, Salmon DP, Colombo M (1985) Extents and limits of the matching concept in monkeys (*Cebus apella*) J Exp Psychol Anim Behav Process 11:35–51

Franz H (2001) Zum Einfluss der Trainingsmethode auf das Lernverhalten von Zwergziegen am Computer. Arch Tierz Dummerstorf 44:553–560

Franz H, Reichart H (1999) Der Feldmonitor – eine neue Möglichkeit der Lernforschung mit Tieren und Ergebnisse bei visuellen Differenzierungsaufgaben von Zwergziegen. Arch Tierz Dummerstorf 42:481–493

Franz H, Roitberg E (2001) Ein Vergleich des Lernerfolges von Zwergziegen bei simultaner Zweifach- oder Vierfachwahlmöglichkeit in visuellen Differenzierungsaufgaben. Arch Tierz Dummerstorf 44:661–669

Franz H, Roitberg E, Löhrke B, Nürnberg G, Dietl G, Kinzelbach R (2002) Visual discrimination learning of group housed goats at an automated learning device. Arch Tierz Dummerstorf 45: 387–401

Friede A (1972) Abstraktionsversuche auf "Gleich" gegen "Ungleich" mit Dohlen. Z Tierpsychol 30:383–404

Giurfa M, Zhang SW, Jenett A, Menzel R, Srinivasan MV (2001) The concepts of 'sameness' and 'difference' in an insect. Nature 410:930–933

Harlow HF (1958) The evolution of learning. In: Roe A, Simpson GG (eds) Behavior and evolution. Yale University Press, New Haven, pp 269–290

Lock AE, Colombo M (1996) Cognitive abilities in a comparative perspective. In: Lock AE, Peters CRE (eds) Handbook of human symbolic evolution. Clarendon, Oxford, pp 596–643

Lombardi CM, Fachinelli CG, Delius JD (1984) Oddity of visual patterns conceptualized by pigeons. Anim Learn Behav 12:2–6

Meyer DR, Harlow HF (1949) The development of transfer of responses to patterning by monkeys. J Comp Physiol Psychol 42:454–462

Moon LE, Harlow HF (1955) Analysis of oddity learning by rhesus monkeys. J Comp Psychol 48:188–194

Noble CS, Thomas RK (1970) Oddity learning in the squirrel monkey. Psychonom Sci 19:305–307

Pastore N (1954) Discrimination learning in the canary. J Comp Physiol Psychol 47:389–390

Pepperberg IM (1987) Acquisition of the same/different concept by an African grey parrot (*Psyttacus erithacus*): learning with respect to categories of color shape and material. Anim Learn Behav 15:423–432

Rensch B, Dücker G (1959) Versuche über die visuelle Generalisation bei einer Schleichkatze. Z Tierpsychol 16:671–692

Robinson EW (1933) A preliminary experiment on abstraction in a monkey. J Comp Psychol 16:231–236

Smirnova AA, Lazareva OF, Zorina ZA (2000) Use of number by crows: investigation by matching and oddity learning. J Exp Anal Behav 73:163–176

Soltysik S, Baldwin B (1972) The performance of goats in triple choice delayed response tasks. Acta Neurobiol Exp 32:73–66

Strong PN, Hedges M (1966) Comparative studies in simple oddity learning 1 cats racoons monkeys and chimpanzees. Psychonom Sci 5:13–14

Thomas RK (1980) Evolution of intelligence: an approach to its assessment. Brain Behav Evol 17:452–474

Thomas RK (1996) Investigating cognitive abilities in animals: unrealized potential. Cogn Brain Res 3:157–166

Thomas RK, Boyd MG (1973) A comparison of *Cebus albifrons* and *Saimiri sciureus* on oddity performance. Anim Learn Behav 1:151–153

Thomas RK, Frost T (1983) Oddity and dimension-abstracted oddity (DAO) in squirrel monkeys. Am J Psychol 96:51–64

Thomas RK, Noble LM (1988) Visual and olfactory oddity learning in rats: what evidence is necessary to show conceptual behavior. Anim Learn Behav 16:157–163

Thompson RKR (1995) Natural and relational concepts in animals In: Roitblat HL, Herbert L (eds) Comparative approach to cognitive science. Bradford Books MIT Press, Cambridge Mass., pp 175–224

Wasserman EA (1993) Comparative cognition: beginning the second century of the study of animal intelligence. Psychol Bull 113:211–228

Wasserman EA, Hugart JA, Kirkpatrick SK (1995) Pigeons show same–different conceptualization after training with complex visual stimuli. J Exp Psychol Anim Behav Process 21:248–252

Williams DI (1967) Discrimination learning in the pigeon in relation to the number of negative stimuli. Anim Behav 15:79–81

Wilson B, Mackintosh NJ, Boakes RA (1985) Transfer of relational rules in matching and oddity learning by pigeons and corvids. Q J Exp Psychol 37B:313–332

Wodinsky J, Bitterman ME (1953) The solution of oddity-problems by the rat. Am J Psychol 66:137–140

Wright AA, Santiago HC, Urcuioli PJ, Sands SF (1984) Monkey and pigeon acquisition of same/different concept using pictorial stimuli In: Commons ML, Herrnstein RJ, Wagner AR (eds) Quantitative analysis of behavior, vol IV. Discrimination processes. Ballinger, Cambridge, Mass., pp 295–317

Zerbolio DJ, Royalty JL (1983) Matching and oddity conditional discrimination in the goldfish as avoidance responces: evidence for conceptual avoidance learning. Anim Learn Behav 11:341–348