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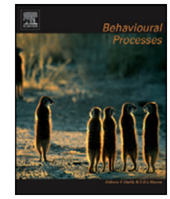

Concurrent recall of serially learned visual discrimination problems in dwarf goats (*Capra hircus*)

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ABSTRACT

Studies of cognitive ability in farm animals are valuable, not only because they provide indicators of the commonality of comparative influence, but understanding farm animal cognition may also aid in management and treatment procedures. Here, eight dwarf goats (*Capra hircus*) learned a series of 10 visual four-choice discriminations using an automated device that allowed individual *ad lib.* access to the test setup while staying in a familiar environment and normal social setting. The animals were trained on each problem for 5 days, followed by concurrent testing of the current against the previous problem. Once all 10 problems had been learned, they were tested concurrently over the course of 9 days. In initial training, all goats achieved criterion learning levels on nearly all problems within 2 days and under 200 trials. Concurrently presenting the problems trained in adjacent sessions did not impair performance on either problem relative to single-problem learning. Upon concurrent presentation of all 10 previously learned problems, at least half were well-remembered immediately. Although this test revealed a recency effect (later problems were better remembered), many early-learned problems were also well-retained, and 10-item relearning was quite quick. These results show that dwarf goats can retain multiple-problem information proficiently and can do so over periods of several weeks. From an ecological point of view, the ability to form numerous associations between visual cues offered by specific plants and food quality is an important pre-grazing mechanism that helps goats exploit variation in vegetation and graze selectively.

1. Introduction

Mammalian species may be expected to have basic learning and problem-solving methods in common, either as a result of shared evolutionary history or as a result of common adaptive processes to the structure of nature (Macphail and Bolhuis, 2001). Although a variety of experimental tasks have been developed to assess learning and memory function in animals, comparable interspecies tests have not been easy to devise. Multiple-problem discrimination procedures like serial exposure to successive problems have provided valuable approaches for investigating basic learning principles (e.g., the 'learning to learn' phenomenon) from a comparative perspective (Thomas, 1986). Furthermore, learning performance in multiple-problem discrimination can serve as a measure for acquisition and retention in comparative studies (Santucci and Treichler, 1990; Treichler et al., 1977). In this approach, which has been referred to as 'concurrent discrimination' (Hayes et al., 1953), the trials on a number of different problems are intermixed, either during problem acquisition or during recall of previously learned problems (Thomas, 1996). Applying this approach, animals' capacity has been tested for retention of information about a large number of object-discriminations over longer time periods (Bakner and Treichler, 1993; Nakagawa, 1992; Treichler, 1984).

In farm animals, most tests of performance in serial (one after the other) or concurrent (at the same time) multiple-problem discrimination have been carried out on horses (Murphy and Arkins, 2007; Nicol, 2002). Various studies reported a significant reduction in the number of trials horses needed to reach a given learning criterion in successive problems, indicating that horses have the ability to use previously learned information to facilitate subsequent learning (Fiske and Potter, 1979; Sappington and Goldman, 1994). Recently, similar results were achieved in dwarf goats (Langbein et al., 2007a). Furthermore, horses, like other *Equidae*, performed quite well in concurrent discriminations (Thomas, 1986).

Conducting similar studies on the cognitive capacity of other domestic animal species is important for various reasons. Cognitive

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processes like learning and memory allow animals to display complex adaptive behavior in dynamic environments (Toates, 2004). The behavior of grazing animals is greatly influenced by the way they perceive, process, and memorize information from their environment. Observation of domestic goats under laboratory conditions clearly indicates that they possess excellent vision and readily respond to visual stimuli (Baldwin, 1979; Blakeman and Friend, 1986). Good vision greatly increases wild goats' chance of survival as they are preyed upon by carnivores and birds of prey in the wild. Furthermore, habitats preferred by feral goats include mountain areas with frequent rocky outcrops and abundant scrubs to use as food and protection (Bullock, 1985). Additionally, goats live in large, complex social groups with a strong linear hierarchy (Langbein and Puppe, 2004), so good visual perception and learning skills would be expected as they are prerequisites for social recognition, as has already been shown in sheep (Kendrick et al., 2001). Feral and wild goats show a highly selective feeding behavior compared to other domestic ungulates (Aldezabal and Garin, 2000). They are able to learn very quickly about spatial and temporal variation of preferred plant species (Provenza et al., 1994). A broader understanding of visual learning abilities, and the memory capacity and stability of goats can help explain the development and stability of learned food preferences in this species.

In farm animal species, a lack of information about learning abilities and memory, or misconceptions about how they learn and adapt their behavior, can result in mismanagement and mistreatment (Held et al., 2002). Another reason for studying learning and memory in farm animals is to evaluate theories relevant to ethical concerns about animal welfare (Croney et al., 2004). Furthermore, understanding the learning flexibility and memory capacity of farm animals is a prerequisite for the future design of species-appropriate devices for cognitive enrichment of housing facilities. As already applied in zoos and recently discussed for farm animals (Bloomsmith et al., 2007; Carlstead and Shepherdson, 2000; Melfi and Thomas, 2005; Swaisgood et al., 2001; Watson et al., 1999), these devices provide long lasting positive effects by combining mental stimulation and a rewarding outcome to facilitate successful coping (Langbein et al., 2004; Puppe et al., 2007). To keep cognitive tasks challenging, they have to be modified and updated regularly, e.g., by varying the rewarded cue (Meehan and Mench, 2007), wherefore knowledge about memory capacity and learning flexibility is essential.

Until now, the vast majority of learning studies have routinely involved training single individuals to perform a limited number of trials per day, organized in separate sessions while separated from their social group and normal housing. However, both separation-related stress and changing the context between the periods of acquisition and retention can impair learning performance (Mendl, 1999; Sondergaard and Ladewig, 2004; Thomas et al., 1985). With this study on serial as well as concurrent multiple-problem discrimination in group-housed dwarf goats, we wanted to broaden the insight into cognitive abilities of animals such as learning flexibility (replacing former cues by new cues), memory capacity (number of cues which can be stored at any one time), and retention time (for how long several cues can be concurrently recalled) under non-laboratory and more naturalistic conditions. We used an experimental approach where the animals could learn individually while remaining in their familiar environment and normal social settings. This was achieved by integrating a fully automated learning device into the animals' home pen. With this experimental design, we wanted to overcome the restrictions of previous learning studies as described above. As the learning device was accessible all day, the animals could decide themselves when to learn and for how long at all stages of the experiment. There was no restriction on individuals with regard to the number of visits to or trials at the learning device or with regard to the overall amount of reward an animal could gain. Furthermore, with such a learning device, we were able to test the individual learning behavior of a large number of animals simultaneously.

2. Animals, materials and methods

2.1. Animals and housing

The subjects of this study were eight female Nigerian dwarf goats (*Capra hircus*, mean age 132 days at the start of the experiment), from a line bred at our institute for over 10 years. The animals were group-housed in an indoor pen (12 m^2), which contained straw litter, a wooden two-floor climbing rack, a hayrack (hay *ad lib.*), and a round feeder to deliver concentrate (300 g per day/animal). The learning device was installed in a separate compartment inside the pen. The device was accessible to all animals 24 h a day, but only one animal could enter the compartment at any one time. Drinking water was available only as a reward for a correct trial at the learning device (see Section 2.6). All animals wore a collar with a responder for individual recognition (Urban, Germany).

2.2. Learning device

The computer-controlled learning device (Fig. 1) has been described in more detail in previous studies (Langbein et al., 2004, 2006). Applying a four-choice design, we presented the goats with different sets of black shapes (discrimination problems), each with one S^+ (positive/rewarded) and three different S^- (negative/unrewarded) stimuli, on a white 38 cm thin film transistor screen (TFT). The screen was protected by a transparent acrylic pane on which four press buttons were mounted. To get a water reward (30 ml), the goats had to discriminate the shape that was predetermined to be the S^+ and press the associated button. The size of single shapes was 7 cm^2 on the screen with a VGA resolution of 640 × 480 pixels. All shapes used were symbols taken from the symbol gallery in COREL 8.0. Each trial was followed by an inter-trial interval (ITI) of 6 s of a black screen, before the shapes were shown rearranged in the next trial. The arrangement of the shapes in consecutive trials followed a pseudorandom series. This series consisted of two different subsets of all 24 possible pattern combinations. By using this series, we ensured that the S^+, as well as the three unrewarded shapes (S^{-1}, S^{-2}, and S^{-3}), were normally distributed in the four

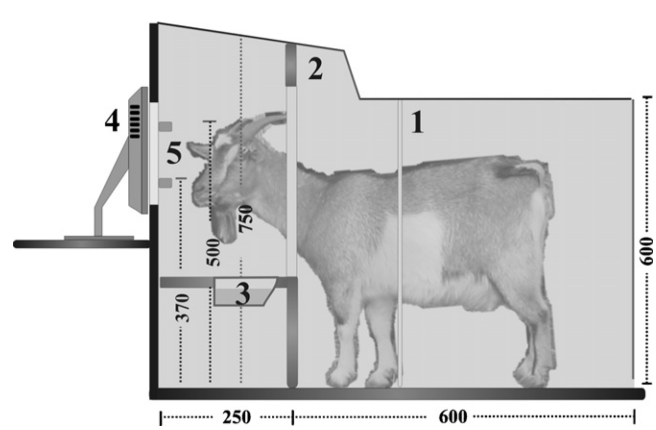

Fig. 1. Sketch and measures (in mm) of the compartment containing the learning device: (1) antenna for individual identification, (2) head gate, (3) water bowl for reward delivery, (4) computer screen for shape presentation (protected by an acrylic pane), and (5) press buttons to choose a shape (mounted on the acrylic pane). The compartment is closed surrounded by opaque walls to avoid observational learning.