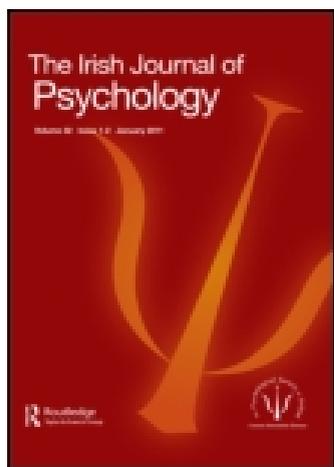


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Multi-modal conditional discrimination in rats: Some preliminary findings

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A new methodology was used to train two rats on a conditional discrimination task that used multi-modal stimuli that differed along a number of sensory dimensions (i.e., visual, tactile and olfactory). Rats were trained across two stages to move from a multi-modal sample to a multi-modal comparison for food reward (i.e., given Wood as sample, move to the Rubber comparison [A1-B1], and given Foam as sample, move to the Carpet comparison [A2-B2]). Having reached criterion in the second stage of training, rats were then exposed to blocks of trials where symmetry probe test trials (B1-A1 and B2-A2) were interspersed with reinforced and non-reinforced baseline trials. The advantages of the methodology for facilitating multi-modal conditional discrimination responding in rats is discussed.

Within the experimental analysis of behaviour, research on conditional discrimination responding usually employs the matching-to-sample procedure (see Dymond, 1995). On a typical matching-to-sample trial, subjects are required to choose between comparison stimuli in the presence of a particular sample stimulus. A variety of stimuli and experimental arrangements have been used to examine both identity matching-to-sample (i.e., reinforcing selection of the comparison that is physically similar to the sample), and oddity-from-sample (i.e., reinforcing selection of the physically dissimilar comparison), in nonhumans including monkeys (D'Amato & Colombo, 1989; Oden, Thompson & Premack, 1988), pigeons (Cumming & Berryman, 1965; Wright, Cook, Rivera, Sands & Delius, 1988; Zentall, Edwards, Moore & Hogan, 1981), marine mammals (Herman & Thompson, 1982; Pack, Herman & Roitblat, 1991), and rats (D'Amato & Salmon, 1984; Iversen, 1993; Thomas & Noble, 1988). Matching- and oddity-from-sample procedures have proven to be reliable methods with which to examine supposedly cognitive processes in nonhumans (Aggleton, 1990; Dymond, 1995).

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In general, most, if not all, of the nonhuman studies concerned with conditional discrimination that employ matching-to-sample procedures have not employed stimuli and/or responses that could be considered analogous to the types of stimuli/responses that occur in the animal's natural environment. Specifically, the majority of researchers appear to have overlooked the potential advantages of designing an experimental context to be as 'naturalistic' as possible in order to facilitate conditional discrimination responding in their research subjects. One exception to this is a study by Wright and Delius (1994), who trained pigeons to dig in different coloured gravel for buried grain. Pigeons soon learned the task (either identity matching or oddity), with acquisition accelerating "100-fold compared with learning in traditional key-peck environments" (Wright & Delius, 1994, p. 108). By combining a stimulus property of the natural world (coloured surfaces) with a "natural" response (digging in gravel) Wright and Delius maintained a steady 90% accuracy rate by as early as the 27th trial. This outcome was in stark contrast to some conventional procedures that result in acquisition in 1,000 to 2,500 trials (see Cumming & Berryman, 1965). These data suggest that providing naturalistic stimuli and responses readily facilitates the acquisition of identity matching and oddity responding in pigeons. However, no published study has attempted to explore the effectiveness of employing 'naturalistic' stimuli (e.g., stimuli that differ along more than one sensory modality) and responses (e.g., food-related behaviour such as foraging, digging and caching) on the acquisition of arbitrary conditional discriminations in rats.

Recent pilot research in the University College Cork Laboratory (Dymond & Barnes, 1995) has set about developing a new methodology for the investigation of arbitrary conditional discrimination responding in rats by employing multi-modal stimuli that differ along a number of sensory dimensions (i.e., visual, tactile, olfactory) and by adapting the experimental context to ensure locomotion between stimuli. Rats foraging for food in the wild will, in the course of searching for, locating, and consuming various food stuffs, traverse a range of surfaces that look, smell, and feel different, and perhaps also make different sounds when traversed. Providing a similar experimental environment may, therefore, facilitate the acquisition of conditional discriminations, and perhaps even allow the researcher to test for the emergence of untaught or novel discriminations in this subject population.

Based on the findings of the pilot research, the present study trained two rats over two stages, on an arbitrary conditional discrimination task using multi-modal stimuli (i.e., Wood to Rubber [A1-B1] and Foam to Carpet [A2-B2]). The primary focus of interest was the effectiveness of the methodology on acquisition of the baseline conditional discriminations.

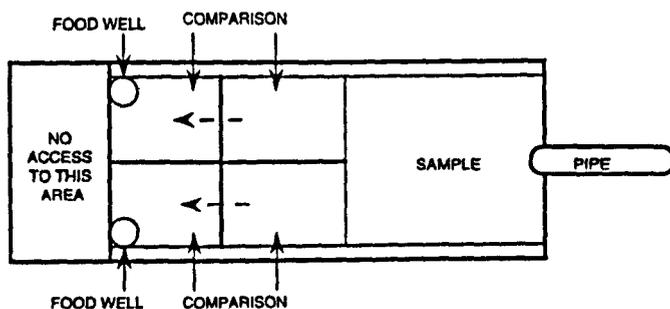
Rats were also exposed to 'symmetry' probe test trials where the sample-comparison configurations were reversed (i.e., Rubber to Wood [B1-A1] and Carpet to Foam [B2-A2]), which were interspersed with baseline and non-reinforced baseline trials, in an attempt to demonstrate the emergence of symmetrical responding following a history of reinforced multi-modal conditional discrimination.

METHOD

Subjects

Two male albino Wistar rats (R2 and R6), seven weeks old at the beginning of the study, were obtained from the Biological Services Unit at University College Cork. They were housed together with water freely available and maintained at 85% of their free-feeding weights by supplemental feedings at the end of daily sessions.

Figure 1. Plan view of the experimental apparatus, with the areas designated for location of the sample and comparison stimuli, and the food wells. Note that the dashed arrows in each of the comparison areas indicate the location of one-way flaps through which the rats entered towards the food wells.



Apparatus and stimuli

The experimental apparatus was a locally constructed white-coloured rectangular-shaped wooden box (150 cm long x 60 cm wide x 30 cm high) positioned on a stand 120 cm above the ground (see Figure 1).

The apparatus was divided into three compartments by 3 cm high lips running the length of the box and the width of the area designated for the sample stimulus, which measured 57 cm x 57 cm. A plastic entrance pipe, 45 cm x 10 cm, protruded 10 cm into the sample area. The entrance pipe was positioned to allow for a gentle incline into the box (i.e., to encourage the rat to enter the sample area).

The area designated for the comparison stimuli measured a total of 60 cm x 60 cm in which two comparison trays could be placed, each measuring 60 cm x 30 cm and divided by a 30 cm high piece of plywood. In the middle of each of the comparison trays, a 30 cm high wall had a 14 x 9 cm hinged one-way door flap added (Figure 1). The dimensions of the one-way flaps allowed adult rats ease of locomotion through them and required a minimum of force (i.e., 0.10 N) to open. Foam buffers, placed on the inside of the midpoint-wall, prevented flap closure from startling the rats.

Two food wells (3 cm in diameter and 2.5 cm high) were pinned to the left and right sides, respectively, of the lips running the length of the apparatus (see Figure 1). Both wells were baited with a 40-mg piece of Red Mills Rodent Cubes®. A wire mesh was placed over the food in one well to prevent access to it. The wire mesh was approximately 0.5 cm above the base of the interior of the food well (i.e., it could not be seen without looking into the well).

The experimental apparatus and the rat's home cage were located in a room where a 12 hour light/dark cycle was in operation with temperature and humidity kept constant. Two fans provided ventilation and masked any extraneous noise.

Stimuli were chosen for their discriminability along as many modalities as possible. Four multi-modal stimuli were used to train two conditional discriminations; Wood to Rubber (A1-B1) and Foam to Carpet (A2-B2). The rubber stimuli were black in colour and covered with moulded grooves, the carpet pieces were light grey long-haired carpet tiles and the foam pieces were light green in colour and 1 cm in diameter. Stimuli were cut to fit the sample and comparison areas.

Procedure

General Experimental Sequence. At the commencement of daily sessions, each rat was weighed and placed in a single cage while the experimenter arranged the configuration of the first trial. No food or water was available in this cage. At the beginning of each trial, the experimenter placed the rat in the entrance pipe from where it proceeded to the sample stimulus. During the experiment both food wells were baited, but a wire mesh inside the incorrect food well prevented access to the food. This 'double baited' procedure (see for example, Thomas & Noble, 1988, Experiment 2; Wright & Delius, 1994, Experiment 2) allowed rats to see and smell the food, whilst ensuring that their behaviour was under the discriminative control of the sample-comparison stimuli and not extra-experimental (e.g., smell) cues.

On each trial, a rat was allowed to move between comparison stimuli, providing that it did not fully enter the interior of the comparison via the one-way flap. This allowed rats to "re-correct" their behaviour by moving from the incorrect to the correct comparison, via the sample stimulus. A response was recorded as either correct or incorrect when the one-way flap closed behind a rat (once closed, a rat could not return to the other side). Every correct response was reinforced with a 40-mg piece of food and followed by an inter-trial interval (ITI) of 30-s, during which the experimenter rearranged the stimuli for the next trial. Following an incorrect response, trials ended without access to food and rats were placed in the single cage for a time-out period of 60-s.

The experimental methodology required that the rats were extensively handled. Apart from handling at the commencement of daily sessions, rats were taken from the experimental apparatus and placed back in the single cage at the end of every trial. The possibility of human interaction through such handling serving as a reinforcer (see Davis & Balfour, 1992), can be ruled out since rats were handled after every correct and incorrect trial.

Familiarisation. For two days, each rat was placed individually in the entrance pipe of the experimental apparatus and was allowed to exit from the pipe and explore the apparatus a total of three times with wood as the sample stimulus and rubber and carpet as comparisons. Once inside the device re-access to the pipe was not allowed (i.e., the interior of the pipe was blocked). No food was present during this stage.

Conditional discrimination training. The day prior to commencing the experiment proper, all food was removed from the rat's home cage. Then, each rat was given two days of pretraining exposure to each of the A-B relations (i.e., A1-B1 and A2-B2) with a 40-mg piece of food present on the surface of the 'correct' comparison, 3 cm in front of the flap door (i.e., on the sample side). In effect, as soon as the rat exited the entrance pipe it was simply required to locate the food visually, without entering through either of the one-way flaps.

Next, there followed two stages of training. In Stage 1, rats were exposed to blocks of 32 trials which presented each of the trial configurations (2 sample and comparison relations and 2 left/right comparison locations) in a quasi-random order, the only constraint being that no trial type could re-occur on consecutive trials. Food was placed just under the flap door (i.e., 1.5 cm on the interior side) and each rat was required to reach a criterion of 90% correct comparison choices (i.e., 29 out of 32 trials

correct) twice consecutively. In effect, Stage 1 simply required rats to discriminate the presence or absence of food under the flaps. Having reached the criterion, rats were then exposed to Stage 2. Now, food was present in both food wells but access was only possible to one food well (i.e., the 'correct' well). A correction procedure was used following incorrect responses in which the experimenter repeated the trial, after a time-out period of 60-s had elapsed, until the subject responded correctly. The criterion was again a minimum of 90% correct comparison choices (i.e., 29 out of 32 trials correct) twice consecutively.

Symmetry probe test trials. On reaching criterion in Stage 2, rats were next exposed to blocks of trials with symmetry probe test trials and non-reinforced baseline probe trials interspersed. In the symmetry probe trials, the positions of the sample and comparisons were switched; rats were presented with Rubber (B1) and Carpet (B2) as samples and Wood (A1) and Foam (A2) as comparisons in order to examine the possible emergence of symmetrical responding (i.e., B1-A1 and B2-A2). Each symmetry probe task was presented twice (2 sample and comparison relations and 2 left/right comparison locations). The number of daily trials was increased to 40 trials, which included 24 baseline A-B training trials, 8 non-reinforced baseline probe trials, and 8 symmetry (B-A) probe trials. Trials were generated quasi-randomly with 3 baseline, 1 baseline probe and 1 symmetry probe trial per block of 5 trials, again with the only constraint being that a trial type could not re-occur on consecutive trials.

During all the baseline probe and symmetry probe trials both food wells were empty. A correction procedure was used following incorrect responses on baseline A-B trials only; incorrect responses on both baseline probe and symmetry probe trials resulted in the ITI and presentation of the next trial.

RESULTS

Acquisition of multi-modal conditional discriminations

The number of sessions required to reach the criterion in Stage 1 of 90% twice consecutively on the A1-B1 and A2-B2 conditional discriminations was 17 (i.e., 544 trials) for R2, and 14 (i.e., 448 trials) for R6 (Figure 2). The number of sessions required to reach the same criterion in Stage 2 was 30 (i.e., 960 trials) for R2, and 20 (i.e., 640 trials) for R6. Following a 10-day unscheduled break in the research, the performance level of R2 dropped below chance level (sessions 19 and 20). The effect of this break was not as pronounced for R6, who correspondingly required less training sessions to acquire the discriminations than R2.

Figure 2. The percentage correct for acquisition of the multi-modal conditional discriminations (i.e., A1-Bland and A2-B2) for R2 and R6. Squared data points above Sessions 18 and 16 for R2 and R6 respectively, indicate the subjects' first exposure to Training Stage 2 (see text for additional details).

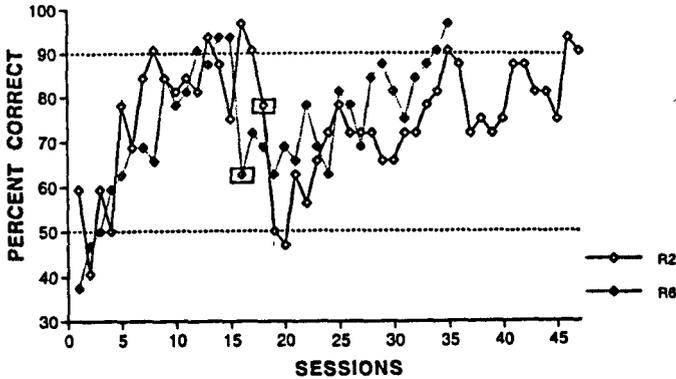
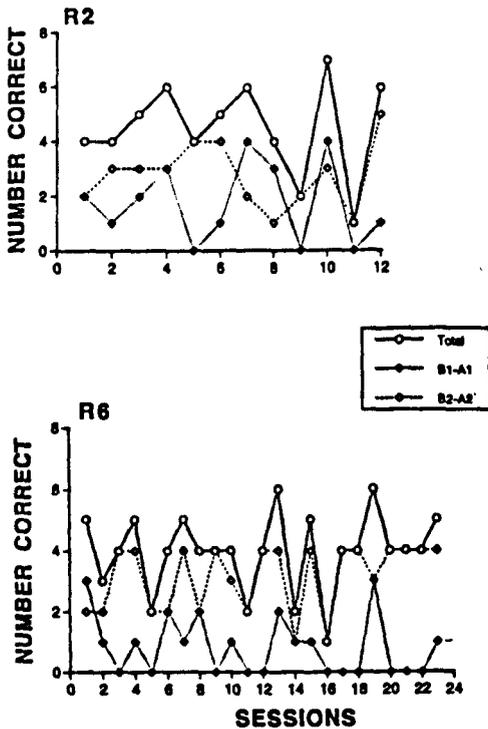


Figure 3. Across session symmetry (i.e., B1-A1 and B2-A2) probe test trial performance for R2 and R6.



Across-session symmetry probe performance

Figure 3 shows the across-sessions symmetry probe trials performance for each rat. R2 demonstrated within-session symmetrical responding (i.e., a minimum of 6 correct responses out of 8 symmetry probe trials) on 3 occasions, with a mean of 56% of probes and 79% of baseline trials correct, while R6 demonstrated within-session symmetrical responding on 2 occasions, with a total mean on the symmetry probe trials at a level expected by chance, and a mean of 72% of baseline trials correct. It is possible that extinction (i.e., the cumulative effect of presenting trials that did not result in access to food reinforcement) influenced the performance of R6, particularly as this subject received twice the number of symmetry probe sessions compared to R2.

Overall, these preliminary results demonstrated that rats acquired, in two stages, a multi-modal arbitrary conditional discrimination. When the directly trained A-B conditional discriminations were introduced as non-reinforced probe trials within blocks of reinforced training trials, baseline levels dropped slightly, and performance on the symmetry trials where sample and comparison relations were reversed (B-A), on average, remained at chance levels.

DISCUSSION

A new methodology was used to train two rats in two multi-modal conditional discriminations. In Stage 2 of the study, in which food was placed in the food wells rather than underneath the comparison flaps, R6 acquired the conditional discrimination (i.e., >90% correct across two consecutive sessions) after 640 trials, and R2 in 960 trials. These acquisition data compare favourably with the results reported by Iversen (1993), in which his three rats required between 4500 and 6000 trials to acquire the conditional discrimination using visual stimuli (steady and blinking lights) presented on nose keys in a standard operant chamber. Interestingly, however, the current acquisition rates are not very different from those reported in a recent study in which rats were trained to pull up strings of different widths (Tomie & Whishaw, 1990). Like our study, the acquisition rates fell somewhere between 500 and 1000 trials. Clearly the data from this and the current study indicate that conditional discrimination responding in rats can be greatly facilitated by providing an experimental context and procedures that depart from the traditional operant chamber.

The absence of symmetrical responding across experimental sessions adds to the growing number of studies conducted on this property of 'stimulus equivalence'. Symmetry has been the most difficult to demonstrate conclusively in a variety of nonhuman species (e.g., D'Amato, Salmon, Loukas & Tomie, 1985; Dugdale & Lowe, 1990; Lipkens, Kop &

Matthijs, 1988; Sidman, Rauzin, Lazar, Cunningham, Tailby & Carrigan, 1982). Reasons for this lack of symmetry are, as yet, unknown. One account offered by Hayes (1989) is that symmetry emerges, at least in part, from a history of explicit reinforcement for responding in accordance with symmetry relations across one or more exemplars. The majority of studies to date (present study included) have not provided this history. Importantly, in studies where symmetry is directly trained (i.e., A-B and B-A) with one or more sets of stimuli, nonhumans have shown symmetrical responding on another 'novel' set (see Schusterman & Kastak, 1993). Perhaps utilising methodologies such as that of the present study will shed light on the nature of symmetry and the reinforcement history necessary to establish bidirectional, or reversible, relations between stimuli in nonhumans (Dymond, 1995).

Overall, the current methodology has several advantages. First, the stimuli used were multi-modal; they each differed along at least three sensory dimensions (i.e., visual, tactile, and olfactory) and thus may have been more readily discriminated from each other than stimuli that differ only along one or two dimensions (i.e., uni-modal). A similar observation was made by Aggleton (1990, p. 86), Rothblat and Hayes (1987, p. 589), Savage (1995, p. 177-178), and other researchers, in discussions of decrements in performance levels in rats on delayed matching-to-sample and delayed non-matching-to-sample tasks with uni-modal visual stimuli. It is of course possible that, in the present study, each rat learned a different conditional discrimination consisting of different combinations of the multi-modal stimulus dimensions. The point remains, however, that the subjects' behaviour readily came under the control of some individual or combinatorial aspect of the sample and comparison stimulus configurations (cf. Iversen, 1993). In effect, if the tactile dimension did not readily assume control during the initial stages of training, the olfactory dimension may have become more salient for the rat, and so on.

Second, the rats could obtain food reinforcement by moving from one multi-modal stimulus to another. This locomotive operant response is one to which rats are well suited, and did not require extensive pretraining or autoshaping, as is typically the case with either lever-pressing or key-pecking in standard operant chambers.

Third, rats could also obtain and eat the food reinforcement while standing on the comparison stimulus, thus the correct comparison and the reinforcer were temporally and spatially contiguous (see also Wright et al., 1988). In contrast, in an operant chamber the comparison is usually not present when the reinforcer is consumed.

Fourth, the rats were allowed to re-choose a comparison (i.e., having entered one comparison, they could move back onto the sample and enter

the second comparison, providing of course that they had not moved through the one-way flap). This aspect of the procedure differs greatly from the standard operant chamber in which responding to a comparison is either reinforced or punished. Subjects are thus not permitted by standard experimental arrangements to 'partially' respond to one comparison (apart from orientation towards the stimulus), and then respond 'totally' to the other, as was the case in the current study.

Fifth, the sample and comparison stimuli were presented simultaneously, and thus the rats could stand on the sample and sniff or touch one of the comparison stimuli at the same time, as well as move between the sample and comparisons (examples of these and other video-taped sessions are available on request from the first author). Although successive presentation is generally considered to be more effective than the simultaneous presentation of samples and comparisons (Wasserman, 1976), it remains to be seen whether the current use of multi-modal stimuli and a locomotive response in rats will provide an advantage for the simultaneous over the successive procedure.

Finally, the current methodology is readily adaptable to other experimental procedures (e.g., response acquisition with delayed reinforcement; see Critchfield & Lattal, 1993; differential outcomes; see McIlvane, Dube, Kledaras, de Rose & Stoddard, 1992; many-to-one and one-to-many stimulus arrangements; see Zentall & Urcuioli, 1993; go/no go discriminations; see Cohen, Grassi & Dowson, 1988), as well as other research areas such as behavioural neuroscience (see Aggleton, 1990).

Clearly, as the above points indicate, the procedures and findings of the present paper suggest significant avenues for future research. Perhaps of greater significance is the attention the present paper pays to 'naturalistic' stimuli and procedures designed to maximise a subjects' behavioural repertoire. As other authors have suggested, lever-pressing or key-pecking are not 'natural' responses of rats and pigeons in the wild and usually require extensive pretraining to establish. Thus, harnessing 'naturalistic' methodologies should allow for investigation of a variety of environmental phenomena and animals responses to them, such as food source depletion and habitat change.

CONCLUSION

The procedure and findings of the present paper clearly show that the further investigation and employment of multi-modal stimuli and responses in conditional discrimination procedures is an area worthy of continued systematic research. Much remains to be done, however, before a definitive conclusion regarding the merits of the present methodology can be drawn. For example, a systematic analysis of the variable 'naturalistic'

is required. Specifically, is it necessary that experimental stimuli play a direct role in the ecological and evolutionary history of subjects or should stimuli be selected on the basis of multi-dimensional sensory properties that, in turn, offer advantages to the researcher interested in studying conditional discrimination responding in nonhumans.

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