Rats do learn XYX rules

Esther Mondragón[1,*], Robin A. Murphy[1,*] and Victoria A. Murphy[2],

[1]*Cognitive, Perceptual and Brain Sciences Research Department, University College London.*

[2]*Department of Education, University of Oxford.*

[1,*]Correspondence: E. Mondragón or R.A. Murphy. Cognitive, Perceptual and Brain Sciences Research Department, University College London. Gower St., London. WC1E 6BT, UK

E-mail contact: e.mondragon@ucl.ac.uk, robin.murphy@ucl.ac.uk

[2]Department of Education, University of Oxford, 15 Norham Gardens, Oxford, OX2 6PY

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In a study carried out with pre-linguistic infants, Marcus et al. (1999) proposed that the XYX sequence learning paradigm constitutes evidence of abstract rule learning related to language that is exclusive to humans. Hauser et al. (2002) found that cotton-top tamarins were also able to learn the sequence and extract a rule, extending the ability from humans to primates. Murphy et al. (2008) experiment 2 showed that rats were also able to discriminate the pattern XYX and to transfer it to novel stimuli. Corballis' article argues against these later results and questions the involvement of this type of learning in human language.

Corballis claims that our rats -- and presumably the argument would extend to babies and cotton-top tamarins confronted with the same kind of task-- may have used a subset of stimuli to solve the rule discrimination. For instance, rats learning that XYX was the reinforced sequence may have matched the identity of the first and last stimulus (X), ignoring the interposed element (Y) and that this would be sufficient to discriminate XYX from YYX or YXX. Corballis' account is not as parsimonious as he suggests because it requires that the rat not only identify each stimulus but also its order or position in the sequence. Moreover, rats must learn which particular subset of elements are relevant among all the possible matching subsets in the sequence and finally they are required to select the precise operation to use, that is, they have to choose a "matching" operation instead of, for instance, a "higher frequency than" operation. Corballis' argument really seems to relate to which kind of rule an animal can learn or which ones might be easier rather than questioning the ability to learn rules.

Corballis acknowledges that his explanation would imply that rats in each of the three groups were behaving on the basis of different learning strategies. Thus, group XYX would have to learn the pair formed by the first and last stimuli, group XXY would have to learn the initial pair, and group YXX the final pair of stimuli in order to be able to discriminate the reinforced from the nonreinforced sequences. Learning by employing different strategies would imply different degrees of difficulty. Learning that YXX is reinforced would be expected to be quite easy because the discriminative stimulus pair is contiguous with food reinforcement, whereas learning about XXY should be more difficult given the delay between the critical stimulus pair and the reinforcement. Last, learning the reinforced sequence XYX should be particularly difficult because it would involve using the first and last stimuli as the discriminative pair. The retention interval between the two elements would retard discrimination and also this retention interval would be filled with a stimulus that would be predicted to interfere with learning. Our study did not find significant differences in the discrimination among the groups.

Corballis challenges the lack of a statistical difference by way of a hypothesized floor effect. Although always a possibility, there is no reason to believe that differential discriminative performance for the different rules (i.e., XYX, YYX or YXX) was masked by a suggested floor effect. The overall levels of responding were quite high giving more than enough room for differences to emerge and the pattern of responding did not reflect chance performance. Animals responded more during the third stimulus than at any other time during the sessions and they responded more on trials that were followed by food than on those that were not.

The rats were not required to produce any particular response to get the reinforcer, nor were they provided with a response choice. Behaviour in this procedure just shows rats anticipatory food checking and cannot be measured as reflecting a binary decision process, correct versus incorrect or go versus no-go response. We did not measure an instrumental response (goal directed) but an elicited response (a Pavlovian conditional response) as Marcus and Hauser did in their experiments in which an unconditional habituation orienting response was employed to measure discrimination. Thus, the percentage of correct responses that Corballis suggests is not only quite an unorthodox measure of Pavlovian conditioning but highly inappropriate to reflect food expectancy; in any case, the percentages obtained are not consistent with the expected degree of difficulty that Corballis' analysis entails. Furthermore, the relatively low cost of responding that this Pavlovian task imposes, together with the fact that all individual stimuli were paired with food, would be expected to elicit responses that partially interfere with the discrimination. Learning at a cognitive level is likely to be much stronger than the acquisition data suggest. This claim is supported by the extinction test data of experiment 2 that showed better discrimination than that observed at the end of training.

Configural pattern learning strategies are also ineffective in solving the discrimination. For example, configural properties such as stimulus identity (whether or not the configuration stimuli are identical) cannot be used as a discriminative cue. When applied to the last two stimuli, this property may distinguish the reinforced rule X(YX) from one of the nonreinforced rules X(YY) but not from the other nonreinforced trained rule X(XY). Similarly, rats could not have solved the discrimination by configuring the first two stimuli since the nonreinforced rule (XY)Y would have been undifferentiated form the reinforced sequence (XY)X.

A third point relates to how the rats might be able to transfer learning. Corballis' favoured theory is that rats may simply 'transpose' the learned relation (Hunter 1953). It could be assumed that Corballis' preference for the use of the term transposition is due to the fact that transposition effects have been explained in terms of stimulus generalization (Spence 1937). However disappointing not being able to embrace the simpler theory might be, we cannot overlook the fact that relative or absolute transposition as described by Hunter only occurs with stimuli that are "**ordered** along a linear scale with regard to **one** feature, such as pitch or intensity" (Hunter 1953, pp. 493; emphasis added). Our stimuli (A = 3.2 KHz tone and B = 9 KHz tone) were not ordered along one single dimension nor could they be linearly scaled (the sequence ABA or BAB does not follow a linear distribution along frequency). Stimulus frequencies both increased and decreased within the sequence. Change in the stimulus frequency from the training sequences to the transfer compounds therefore could not follow a transpositional monotonic relationship, such as bigger, darker, etc. Hence, animals could not discriminate or transpose on the basis of a unique orderly dimension such as the stimulus frequency. The position of the elements per se (first, second, third) was also uninformative. Discrimination could only be based on the relationship between frequency changes and the relative position in which they occurred within the sequence. The total amount of frequency change has also to be excluded as a discriminative cue. All the training sequences were formed with the same elements and hence have identical mean frequency variation. Summing up, the stimuli did not change in an orderly, linear fashion, continuously up or down, with regard to one feature. The kind of stimulus relationship employed in our research is not described by Hunter. Tunes may "transpose" to a different key as Corballis suggests but this musical metaphor is just that, a metaphor. Tune transposition cannot be directly derived from Hunter's theory.

Corballis also takes issue with details of our narrative, task and stimuli that he claims are inconsistent with aspects of human language. For instance, Corballis considers that our example of common rule use in humans, grammaticality judgements based on word order, bears no relation to our study. The example "the dog bit the woman" was introduced as illustrative of what a rule, grammatical or otherwise, is and to show that this kind of rule, as language learning does, involves constraints on the temporal ordering of events. We made no claim that rats learned linguistic categories (e.g., verb or object), grammatical rules or even that language learning is the only human cognitive domain in which temporally constrained rules are important (in fact we explicitly stated that it was not) and we certainly did not attempt to teach rats human language. We did investigate the XYX sequence learning in rats and found evidence suggesting that these animals are able to learn to discriminate this type of sequences and to transfer this knowledge to novel stimuli. The ability to transfer showed that they learn something about the structural information of the sequence and does not reflect simple stimulus generalization. We are not, however, proposing a departure from standard learning theory. We have in fact sketched elsewhere an explanation based on associative principles (Murphy et al. 2009).

We did not state the complexity or language specificity of this task. Marcus and collaborators argued that XYX sequence learning in infants reveals rule learning and that this learning is required for human language (Marcus et al. 1999) and perhaps is an ability restricted to primates (Hauser et al. 2002).

Our experiments showed that the same rules that, despite Corballis' claims, are still reported as evidence of abstract rule learning (Marcus et al. 2007; Scott et al. 2009) were also learned by rats. Whether or not such rules are accepted as being at the core of grammar learning in humans (Hauser et al. 2002) or constitute a grammar of any type, or whether the ability to generalize rules has evolved specifically for language acquisition (Hauser et al. 2002) are issues beyond the scope of our research. Nevertheless, the fact that mammals like rats can acquire rules that imply at least some level of abstraction and are considered to be involved in language learning should certainly have implications for any debate on the evolution of language and should be in accordance with an evolutionary perspective of cognition.

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