

The logic of the stimulus

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Received: 30 August 2005 / Revised: 3 July 2006 / Accepted: 4 July 2006 / Published online: 15 August 2006
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Abstract This paper examines the contribution of stimulus processing to animal logics. In the classic functionalist S-O-R view of learning (and cognition), stimuli provide the raw material to which the organism applies its cognitive processes—its logic, which may be taxon-specific. Stimuli may contribute to the logic of the organism's response, and may do so in taxon-specific ways. Firstly, any non-trivial stimulus has an internal organization that may constrain or bias the way that the organism addresses it; since stimuli can only be defined relative to the organism's perceptual apparatus, and this apparatus is taxon-specific, such constraints or biases will often be taxon-specific. Secondly, the representation of a stimulus that the perceptual system builds, and the analysis it makes of this representation, may provide a model for the synthesis and analysis done at a more cognitive level. Such a model is plausible for evolutionary reasons: perceptual analysis was probably perfected before cognitive analysis in the evolutionary history of the vertebrates. Like stimulus-driven analysis, such perceptually modelled cognition may be taxon-specific because of the taxon-specificity of the perceptual apparatus. However, it may also be the case that different taxa are able to free themselves from the

stimulus logic, and therefore apply a more abstract logic, to different extents. This thesis is defended with reference to two examples of cases where animals' cognitive logic seems to be isomorphic with perceptual logic, specifically in the case of pigeons' attention to global and local information in visual stimuli, and dogs' failure to comprehend means-end relationships in string-pulling tasks.

Keywords Functional psychology · Gestalt psychology · Comparative psychology · Global vs. local cues · Means-end understanding

Introduction: Stimuli come first

This special issue of *Animal Cognition* is devoted to the question of “animal logics.” The claim of the present paper is that any consideration of that question needs to start with a consideration of the logic of the stimulus. We will spell out our reasons for making that claim in the rest of the Introduction, but they can all be summarised by the simple statement that Stimuli Come First. There are a number of distinct senses in which this is true, and we will expand on them in order. To summarise in advance, we will argue that stimuli come first in the order of information processing, in the order of science's acquisition of understanding of information processing, and in the order of phylogenetic emergence of information processing.

The claim that stimuli come first may seem a surprising one to make in the context of animal cognition. Distinctively cognitive approaches to behaviour, whether of animals or of humans, can be characterised as taking an “S-O-R” approach, contrasting with the “S-R” approach of behaviourism (Woodworth 1929). That is, between the stimulus (S) and the corresponding response (R) stands the organism (O). Within the organism is where cognitive processing takes place, en-

This contribution is part of the special issue “Animal Logics” (Watanabe and Huber 2006).

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abling a response to stimuli that depends on the organism's past experience and its ability to think and calculate. Radical behaviourism rejects the idea that the "inside story" can ever be known or indeed interesting (Skinner 1969, Chap. 9); cognitive psychology, in contrast, insists that if behaviour is to be predicted accurately, intra-organismic cognitive processes must be understood. This stress on the intervening organism seems to downgrade the importance of the stimulus in the causation of behaviour and therefore in our understanding of behaviour. In the present paper, however, we are arguing that while a cognitive approach necessarily stresses the organism's role in the causation of behaviour, it remains true that stimuli come first, in at least the three senses listed above. We shall now explore each of these in a little more detail.

First and most fundamentally, before cognitive processing can occur, something must be perceived. That something is what we call a stimulus (and it follows that something that cannot be perceived by a particular organism, like ultraviolet light for a human, is not a stimulus for that organism). In simple experimental situations, there is an obvious stimulus within every trial: it is the occurrence of a distinctive stimulus that starts the chain of cognitive processes that eventually gives rise to a differentiated response. Of course, some stimuli may not be perceptible by the observer, for example because they are interoceptive. Even with that caveat, however, in some experimental paradigms the initiating stimulus may not be very obvious, so that responding appears to be "spontaneous", not elicited by any particular stimulus. That is true, for example, of free operant responses, and more strikingly of truly creative responses, which we assume emerge from a process of cognitive reflection. But though operants were born free, analysis shows that they are everywhere in chained schedules of reinforcement—there are stimulus changes that set the occasion for different types of response to be emitted. Another experimental situation that seems at first sight to involve spontaneous response is problem solving, a paradigm case for cognitive analysis. In his discussion of so-called insightful behaviours, Köhler (1927) referred to cases where an animal retires from a test situation and then returns with a fully fledged solution to a problem. But this is only spontaneity in a limited sense: if we look across a longer time span than across the single experimental trial, we can see that in this case too there was certainly an initiating stimulus—the original presentation of the problem.

We conclude that within the classic functionalist approach to cognition, which Woodworth (1929) developed but which has remained the foundation for much work in cognition since, stimuli provide the essential raw material for the determination of action. They do not, of course, determine action by themselves. The organism applies its distinctive cognitive processes—its own logic—to the stimulus material; and intra-organismic processes may mean that the effective stimulus is not the stimulus that is present at the moment of action.

From the point of view of animal cognition, we must recognise that the action that is taken in response to a stimulus will depend on the way that stimulus has been represented, and the memories of other stimuli that the animal holds. To continue with the example used above, the way chimpanzees respond to insight problems does not depend only on the problem set, but also on their previous experience of similar tasks that may be crucial to its solution (Birch 1945). Such contributions from representations and memories are all part of the organism's contribution to the S-O-R formulation. But according to that formulation, organisms do not and cannot respond in a stimulus vacuum.

The second sense in which stimuli come first concerns the behaviour of psychologists as much as the behaviour of the animals we study, and it provides the springboard for the remainder of the present paper. Across the history of psychology, it has been true that our understanding of peripheral, perceptual processes has almost always been more advanced than is our understanding of deeper, cognitive processes. This is partly because perception is linked to the physical dimensions of the stimuli, of which we generally have a sophisticated quantitative analysis. But it is partly because perception is simply more accessible, at least to the outside observer, so the analysis of perceptual processes has been easier and more certain than is the analysis of cognitive processes. What we know about stimulus analysis therefore supplies a model, or a hypothesis, for what we should like to know about cognitive analysis.

This approach was taken to its highest pitch in Gestalt psychology. According to the Gestalt system, an understanding of the stimulus is essential to an understanding of the organism's response for two fundamental reasons. On the one hand, the internal logic of the stimulus may determine the response that can be made to it. The structure of the stimulus may constrain or bias the way that the organism addresses it. A physical, geometric description of the stimulus that does not take account of the relevant Gestalt laws will simply not represent what the stimulus is to the organism. On the other hand, perceptual analysis provides a functional model for cognitive analysis. The Gestalt psychologists expected that brain structures and processes would be isomorphic with structures and processes of the stimulus world, at least in a functional sense (e.g. Köhler 1969, p 92ff). This claim was speculative when first made, and though it has its modern defenders (e.g. Lehar 2003), to most researchers it now seems too weakly grounded in evidence to be sustained. What remains true, however, is that perception and cognition are functions of the same nervous system, so it would not be surprising if they share some properties. Even if we must abandon the Gestalt idea of isomorphism as a law, it is still useful as a hypothesis.

The final sense in which stimuli come first is phylogenetic. There is some evidence that perceptual analysis emerges ear-

lier than does cognitive analysis in evolution. While the idea of encephalisation of function is rarely discussed nowadays, the evidence that supported it has not gone away. To take the now classic example, animals that we believe to be more primitive, like frogs, seem to do kinds of processing, such as the extraction of contours, in their perceptual organs whereas organisms from more recently evolved taxa, like cats, do similar processing in the brain (compare Lettvin et al. 1959 with Hubel and Wiesel 1959). If this principle holds true in general, it lends support to the idea that cognitive processes may mirror perceptual processes, because cognition uses brain structures and processes that first evolved to subserve perceptual functions. This would be consistent with a common phenomenon in evolution, the re-use of established mechanisms and structures rather than the elaboration of totally new ones; nature is “niggard in innovation”, as Darwin (1975, p 471) remarked. So the kind of representation of a stimulus that the perceptual system builds, and the kind of analysis it makes of this representation, may not only provide a theoretical hypothesis about the synthesis and analysis done at a more cognitive level—it may also, in evolutionary history, provide a working prototype.

The difference between the results of Lettvin et al. (1959) and Hubel and Wiesel (1959) is a reminder of a fact that needs to be taken into account as we proceed to explore these various ways in which stimuli come first. The study of animal cognition is inevitably a comparative study, in two distinct senses—senses that have often been thought to be in conflict.

In the first place, because animal cognition has often taken over theories and models from human cognitive psychology, there is always an implicit comparison between humans and the species under study. The study of animal cognition, as it is currently conducted, is thus in an important sense anthropocentric. Leading researchers in the field have differed on the question of whether this is a good thing or even acceptable. Some, such as Wasserman (1993), explicitly support a programme of comparison between human cognition and animals as phylogenetically remote as pigeons. Others, such as Kamil (1988) and Shettleworth (1993) reject this approach as anthropocentric, a tendency that Shettleworth traces back to Darwin (1871). They argue instead for an ecological programme, involving comparisons of closely related organisms, so that the influences of ecological niche on cognition, and hence the evolution of cognition are explicitly taken into account.

Like Emery (2006), we have sympathies for both the anthropocentric and the ecological approach, and feel that what is needed is a combination of the two. Critics of the anthropocentric approach do not always give enough weight to the fact that we know so much more about human cognition than the cognition of any other species, so that at the very least human cognition is a fertile source of hypotheses

about animal cognition. But if the anthropocentric approach is to be useful, we believe that it needs to be adopted openly and taken seriously. In particular, we would argue that if we are going to have comparisons between human and animal cognition, they should be made explicitly rather than being left implicit; and they should be made on the basis of experiments that are as similar as possible in parameters and procedures for humans and animals. It is a well-worn argument that it is impossible to make conditions identical for any two species in any psychological experiment (cf. Bitterman 1975), let alone for humans and other species in a cognitive study. In our view this difficulty has been used as an excuse for making comparisons between human and animal studies that involved quite unnecessary procedural differences. We have shown (Goto et al. 2004, and further unpublished work in our laboratory) that when such differences are removed, results from humans and other animals can become much more similar.

Whatever the strengths of the anthropocentric approach, however, the demands of the ecological programme have to be considered as well. No subject species is just an animal; it is always an animal of a particular taxon, adapted to life in a particular ecological niche. In terms of the fundamental S-O-R model, the logic that the organism brings to the problem will vary from organism to organism. It will vary between individuals of the same species, and such variations explain much of the non-uniformity of behaviour even given the same stimulus inputs. More significantly for the analysis of animal cognition, however, it is likely to vary between taxa, in ways that it may be possible to relate to the phylogenetic history or the ecological niche of a species or other taxon. That is why a full analysis of animal cognition has to be grounded in comparative, evolutionary and ecological considerations as well as in a consideration of the cognitive demands of a given task (cf. Kamil 1998; Shettleworth 1998).

The difference between anthropocentric and ecological research programmes in comparative cognition is important. But on some points, they lead to the same conclusions. In particular, both programmes require that every step of our core argument about stimulus priority should have a comparative dimension. The Gestalt laws of perception may structure the stimulus in taxon-specific ways, because the perceptual apparatus differs between species. The constraints and biases that perception builds into cognition must thus also be expected to be taxon-specific. Even the very notion of the stimulus is necessarily taxon-specific, because a stimulus can only be defined relative to a particular organism's perceptual apparatus, and in general this apparatus is taxon-specific. So, for example, ultraviolet light is not a stimulus at all to a human, but it is to a pigeon (Wright 1972). And if cognitive mechanisms are modelled on perceptual mechanisms because they are processes of the same nervous system, they may differ between taxa in so far as the nervous systems of different

taxa differ. Even if there are no underlying differences of nervous machinery, perceptual analysis may still be taxon-specific, and if so, perceptually modelled cognitive analysis will be taxon-specific also. Thus, the logic of the stimulus will always be a taxon-specific logic, with taxon-specific implications for subsequent cognition.

The next two sections of this paper will use two specific examples to explore in more detail these different ways in which stimuli come first within the area of animal cognition. In the light of the points just made, it should not come as a surprise that both examples involve behaviour and hypothetical underlying cognitive processes that are, on the one hand, taxon-specific, and on the other hand, compared with those of humans.

The local view in pigeon visual cognition

As a first example of the taxon-specific ways in which the structure of the stimulus influences cognition, we shall consider the accumulating evidence that pigeons' behaviour towards complex visual patterns is controlled by local, detailed information under conditions where humans are more influenced by global features. The result of this bias is that pigeons are likely to parse visual scenes quite differently from humans, and a variety of apparently anomalous experimental results in pigeon visual pattern recognition may be explained by this tendency.

Cerella (1980) first hypothesized that pigeons discriminate patterns based extensively on local features, whereas humans in general place more significance on global features, on the basis of his demonstration that pigeons' recognition of the cartoon character "Charlie Brown" was unimpaired by transformations such as occlusion, partial feature removal and scrambling of parts. Studies using different kinds of stimuli (e.g. Van Hamme et al. 1992; Wasserman et al. 1993) have cast some doubt on the generality of Cerella's conclusions, and subsequent studies with stimuli similar to Cerella's have shown that his results were more extreme than is typical, perhaps because he used cartoon characters rather than natural photographs (see Watanabe 2001a). However, as Kirkpatrick (2001) and others have noted, Cerella's generalisation results are what would be expected if pigeons focus on the local details of an image at the expense of its global form. Ghosh et al. (2004) argued that this tendency is best described as a bias, for pigeons, towards processing higher spatial frequencies than humans, or giving greater weight to them in stimulus analysis, but it could also be that the local and global features of a scene are defined relatively rather than in terms of absolute spatial frequency bands.

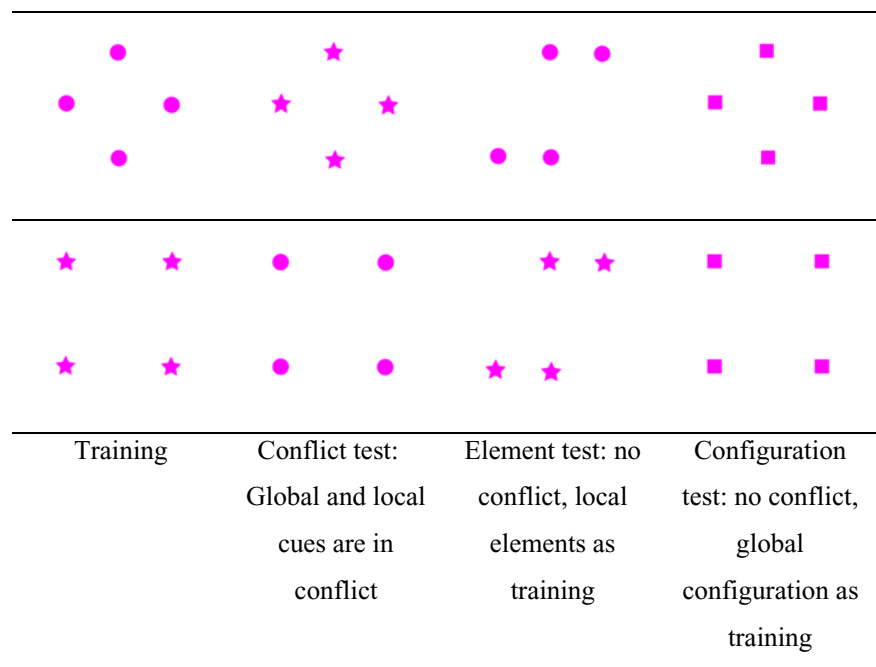
Two distinctively different approaches have been used to examine this local dominance hypothesis. Some studies have used hierarchical stimuli, in which global configuration

and local elements can be segregated and the discrimination of each studied separately, whereas other studies have used pictorial stimuli and examined the effect of various image manipulation techniques such as spatial frequency filtering.

Direct evidence of local dominance in pigeon visual cognition includes an experiment by Cavoto and Cook (2001). They used stimuli that were pioneered by Navon (1977), which can be described at two hierarchically distinct levels, for example a letter H made up of numerous small letter Ss. Response to such stimuli can either be determined by the local elements or by the global configuration; Ghosh et al. (2004) argue that these correspond to dominance by high and low spatial frequencies respectively. If discrimination is first established between stimuli that differ both in configuration and elements, dominance can be tested using transfer stimuli that use either the configurations, or the elements, from the training stimuli. Navon, and many other researchers since, have found that in such tests people tend to respond in accordance with the configuration. However Cavoto and Cook found that pigeons responded in accordance with the elements. Goto (2004) extended these experiments, avoiding the use of letter forms (which obviously mean more to literate humans than they do to pigeons) and some other potential artefacts, and replicated Cavoto and Cook's results. Figure 1 shows some of the stimuli used in Goto's experiments. These papers implicitly suggest that pigeon visual cognition is different from that of humans in terms of relative importance of global and local features.

There is also a substantial evidence of dominance by local information in pigeons in experiments with pictorial stimuli. In addition to the original demonstration by Cerella (1980), Aust and Huber (2001) showed that local details were important in pigeons' discrimination between photographic images with and without people in them, and Matsukawa et al. (2004) found a similar result with cartoon images, though they showed that sufficient fragmentation would produce some generalization decrement, so that global cues must also have some importance. Ghosh et al. (2004, Experiment 1) trained pigeons to discriminate images of dogs from cats, using stimuli similar to (in some cases, identical with) those used in a habituation/dishabituation experiment with human infants by Spencer et al. (1997). Once the birds had mastered the discrimination, they were exposed to chimeras (cf. Cook et al. 1990) in which the heads of dogs were transferred to the bodies of cats and vice versa. This test mirrored one carried out by Spencer et al., who found that infants who had become habituated to dog but not to cat images showed renewed interest in chimeras with cat heads on dog bodies, but not in those with dog heads on cat bodies. Thus, their visual cognition was dominated by the head region of the animal stimulus. The pigeons, however, showed an opposite effect. They were trained to respond to dog images and not to cat images, and in transfer tests they responded to chimeras that

Fig. 1 Hierarchical stimuli used in Goto's (2004) replication of Cavoto and Cook (2001). Pigeons were trained to discriminate between the two stimuli in the left-hand column, and tested with the remaining stimuli



had dog bodies and cat heads more than to those that had dog heads and cat bodies. To the human eye, this appears to contradict the generalisation that pigeon visual cognition is dominated by high spatial frequencies, since for humans, the important local detail in an animal image is mainly found in the head (more specifically, the face) region. However Ghosh et al. showed by Fourier analysis that objectively, the proportion of energy in higher spatial frequencies was actually higher for the rear half of the animal image than for the front half. The impression that the local information is concentrated in the face of an animal must therefore be just that, an impression: Ghosh et al. argued that it results from a bias due to the human special interest in faces (it is reasonable to assume that the face of a cat or dog is enough like a human face to elicit a similar response). One might predict, therefore, that a person who suffered from prosopagnosia would show behaviour towards one of these chimeras that would be more like that of a pigeon than that of Spencer et al.'s infants, though the pigeon's high spatial frequency bias might still produce a different response. Ghosh et al. couched their argument in terms of spatial frequency bands, but it could also be expressed in terms of global and local properties.

Although these studies suggest that there are differences between human and pigeon visual cognition, the comparisons between the two species have generally been indirect. In unpublished work from our laboratory done in collaboration with Andy Wills and Fraser Milton, we have used image manipulation techniques under, so far as possible, identical conditions with humans and pigeons. The stimuli were cat and dog faces as used by Ghosh et al. (2004, Experiment 2). As in previous studies, we found that pigeons were relatively

resistant to removal of low spatial frequency information, though it did have some effect, but more sensitive to the removal of high frequencies. Surprisingly, however, humans showed a rather similar pattern of disruption, suggesting that some of the differences previously detected may have been due to procedural differences rather than true inter-specific differences in visual cognition. This is in accordance with a report by Watanabe (2001b) that pigeons were not differentially affected by different degrees of a mosaic manipulation, and therefore that dominance by high spatial frequencies may not be a complete account of pigeons' image processing.

Is there further evidence of a true species difference? One striking demonstration of the difference between the human and the pigeon's construction of the visual world comes from a comparison of two papers, recently published by Kelly and Cook (2003) and Fujita and Ushitani (2005). Both experiments used tasks in which pigeons and humans had to search for distinctive items in an array of similar items. In Kelly and Cook's experiment, humans showed a superiority on one class of stimuli that the pigeons found more difficult, while in Fujita and Ushitani's experiment, humans showed an inferiority that pigeons did not. Both experiments, however, demonstrate the greater importance of local processes in pigeon compared with human visual cognition.

Kelly and Cook (2003) used stimuli like those shown in Fig. 2. The subjects were exposed to tilted-line stimuli that were shown either on their own, or in the context of a pair of further lines set at a right angle. For humans, putting the tilted line into this context (so that the discrimination between tilts became a discrimination between a tri-

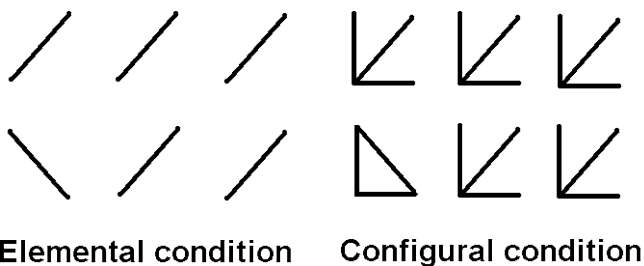


Fig. 2 Line-tilt stimuli used by Kelly and Cook (2003), with right-angle context absent (elemental condition) and present (configural condition)

angle and an arrowhead) made the task much easier. For pigeons, it made the task harder, as though meaningless interference had been added to the displays. Clearly these results are consistent with the view that pigeons respond to the elements of a visual scene whereas humans respond to configurations.

In Kelly and Cook's experiment, adding context effectively hid the stimuli for pigeons but revealed them for humans. In the experiment of Fujita and Ushitani (2005), however, the reverse happened. A number of authors have tried and failed to get evidence that pigeons experience the same kind of visual completion as humans do, when faced with a stimulus that is a familiar form with a small part occluded in some way. For example, Sekuler et al. (1996) could not find any evidence that pigeons saw a bar that was crossed by a second bar as anything other than two short, disconnected, parts. Fujita and Ushitani went further and found positive evidence that pigeons do not complete occluded stimuli, by using a visual search task, in which the subjects had to pick out notched diamonds from complete ones.

Because of our tendency towards visual completion, humans doing this task find it harder to spot the stimulus in which a square nestles exactly into the notch so that the diamond can be seen as an occluded, unnotched figure (the middle stimulus of the bottom row of Fig. 3), than either of the other stimuli. Pigeons, however, show no such difficulty.

Another classic example of a difference between pigeon and human visual cognition is Hollard and Delius's (1982) demonstration that pigeons, unlike humans, do not show enhanced latency for matching two images when they are presented at different orientations (see also Delius and Hollard 1995). Hamm et al. (1997) claimed to show mental rotation in pigeons, but their experiment did not involve comparisons between two concurrently present stimuli, so it did not test for the effect in pigeons under the conditions in which it is usually demonstrated in humans—an example of the failure to make precise comparisons that we alluded to above. Hollard and Delius's results are just what would be expected if pigeons' behaviours were under the control of local information rather than overall shape.

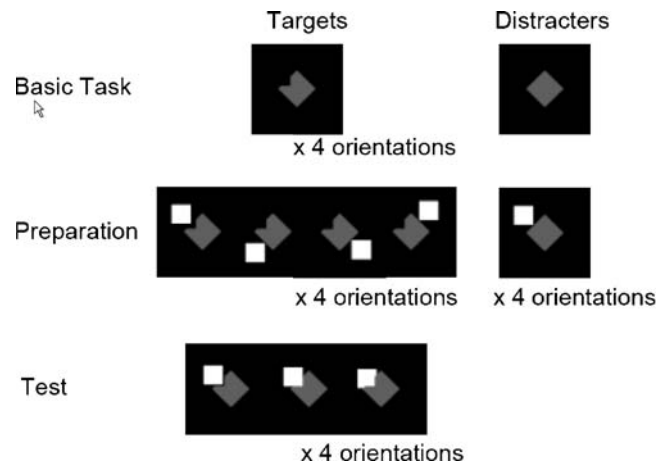


Fig. 3 Stimuli used in Fujita and Ushitani's (2005) experiments on visual completion. The areas shown here in grey were coloured red for presentation to the pigeons. In the Basic Task the pigeons were trained to respond to notched diamonds (Targets) and ignore unnotched diamonds (Distractors); in the Preparation task, they were trained to maintain this discrimination despite the presence of white squares; and the Test phase examined the impact on this task of the relative position of the square and the notched diamond

A final, more recent example of local predominance is Goto and Lea's (2003) demonstration that when pigeons were trained to discriminate movie sequences in which an object moved in front of a background or the background moved behind the object, background movement was far more readily learned, even though object movement seemed much more salient to the experimenters. If the pigeon's visual cognition is predominantly controlled by small details, there are a number of reasons why the background cues would predominate in these stimuli: at its simplest, the background occupies a larger area and therefore contains a greater number of local details.

The converging evidence from these studies shows that in a good many situations, pigeons' relative response to different visual stimuli cannot reliably be predicted from the typical human response to the same stimuli. That generalization is in fact more important than is the hypothesis that these situations can be unified by the concept of local predominance in pigeon vision, and as we have seen, that hypothesis remains open to some question. For even if local predominance is not the explanation, it does seem that in general visual scenes are not parsed in the same way by pigeons as by humans, because the Gestalt laws operating for a pigeon are not the same as those operating for humans. The objects that are salient within a visual scene for humans may not be salient for pigeons—indeed, they may not even be present for them. The logical relations within the stimulus, and the possible operations that can be performed on them, may therefore be completely different for pigeons than those that apply to humans looking at the same stimuli.

These results of course pose a major question. For reasons of experimental convenience, much of the research reported here has been performed on pigeons. But when we find a difference between human and pigeon visual cognition, we do not know whether that is due to a general difference between mammals and birds, or to something peculiar to pigeons and a few relatives, or to something that marks off humans from all other animals. Any of these would be possible, and to date we have only limited information to suggest which is right. Experiments similar to that of Cavoto and Cook (2001) on hierarchical stimuli have been carried out using baboons (Deruelle and Fagot 1998; Fagot and Deruelle 1997), rhesus monkeys (Hopkins and Washburn 2002), capuchin monkeys (Spinozzi et al. 2003), chimpanzees (Hopkins 1997; Fagot and Tomonaga 1999; Hopkins and Washburn 2002), and a bottle-nosed dolphin (Pack et al. 2002); all the monkeys tested have shown the same kind of local predominance as Cavoto and Cook's pigeons, while the dolphin (which was discriminating by echolocation rather than vision) showed global predominance, and the evidence for chimpanzees is equivocal. Similarly with mental rotation; experiments with baboons (Vauclair et al. 1993) and a sea lion (Mauck and Dehnhardt 1997) have reported evidence of the same kind of mental rotation as is seen in humans. Given the long history of independent evolution, and the known differences in visual neuroanatomy, between birds and mammals, there has been a tendency to assume that the major differences lie between the two classes. But there is as yet no evidence to confirm this guess, and what causes these species differences remains an open question; it could be something quite specific about the ecological niche of either pigeons or humans, or the group to which each species belongs. Further ecological and comparative studies will be required to understand whether these differences of stimulus logic are the result of long-established phylogenetic differences in neural organisation, or detailed adaptation to particular ecological niches.

The infantile means-end logic of dogs

For a second example of the taxon-specific ways in which the structure of the stimulus influences cognition, we shall consider some recent work on means-end logic in dogs. The study of means-ends relationships is one of the oldest themes in animal cognition, lying behind Thorndike's (1911) early work on problem-solving, Köhler's (1927) studies of insight, and much else. It is also an important element in the study of human cognitive psychology, with true understanding of means-end relationships being diagnostic for the achievement of stage IV of the sensori-motor phase of cognitive development in Piaget's scheme (see Piaget and Inhelder 1969). Following the important review by Doré and Dumas

(1987), there has been increasing interest in trying to bring these two fields together.

A classic experimental situation for studying the understanding of means-end relationship is to provide the subject with a desired object that is out of reach, but connected by some means to something that the subject can reach. Humans can solve this problem at about the age of 8 months (for recent demonstrations, see Willatts 1999; Munakata et al. 1997). Köhler used this situation with chimpanzees, and his results have been confirmed with more modern techniques by Spinozzi and Poti (1993). Hauser et al. (1999, 2002) successfully used a closely related task with cotton-top tamarins.

However, merely pulling in an object on the end of a string is not a satisfactory comparative test of cognitive ability; some species are much better adapted, both morphologically and ecologically, for such tasks. Failure to pull in strings spontaneously in animals that can easily be trained to perform the task might, perhaps, indicate a failure of means-end understanding, but success does not necessarily indicate its presence. The most interesting experiments are therefore those where more than one string is available, and the animal's task is to choose the correct one; such tasks potentially reveal whether an animal perceives a means-end connection in the same way as a human. For example, Adams (1929) gave an early and convincing demonstration of the functional use of strings by cats. More recent experiments by several authors have found evidence for insightful string-pulling on several species of psittacid (Ducker and Rensch 1977; Funk 2002; Pepperberg 2004; Huber and Gajdon 2006) and in ravens (Heinrich 1995). Although not all these experiments presented multiple or patterned string problems, they all attempted to control for any general tendency of the subjects to investigate and pull strings. Their results suggest that means-end understanding may be found among at least some birds, though earlier studies on more typical songbirds (e.g. Vince 1961) found no consistent evidence of insightful solution of the problem.

Dogs would seem to be good subjects for experiments on string-pulling. They have a reputation for general intelligence (Eddy et al. 1993; Nakajima et al. 2002), they were popular as a subject species in the early period of comparative studies of cognition when string-pulling was a widely used task, and most dogs have everyday experience with string-connection situations through walking on a leash. Surprisingly, however, there are no convincing demonstrations that dogs understand means-end relationships in string-pulling tasks. Scott and Fuller (1965) demonstrated that puppies readily learned to pull in a string that had food at the end of it, but since the puppies could not see the food until they had pulled in the string, their behaviour could only be a learned operant, and the experiment does not test whether they had a spontaneous or indeed any understanding of the means-end relationship implied by the string. Earlier studies such

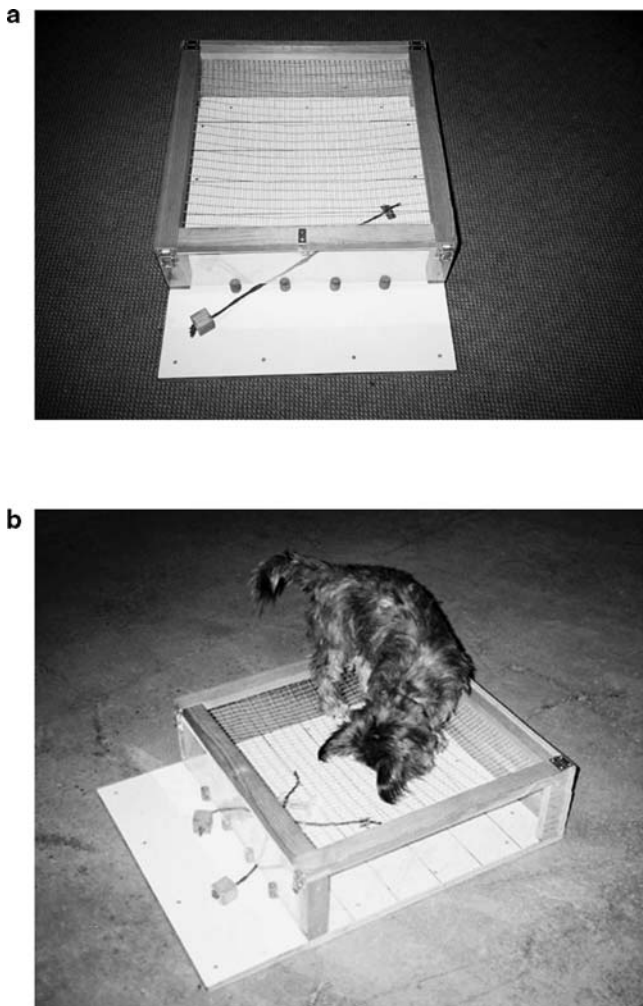


Fig. 4 **a** Apparatus used by Osthaus et al. (2005) to study means-end comprehension in dogs. **b** A dog failing to make use of the string

as those of Shepherd (1915) and Fischel (1933), which did place the food so it was in view at the beginning of the trial, used small numbers of subjects and gave conflicting results.

Accordingly, we investigated string-pulling in dogs systematically, using the apparatus shown in Fig. 4 (Osthaus et al. 2005). One or more strings led into an enclosed frame, where they might be attached to a dog treat. At the accessible end, the strings were tied to blocks which the dogs could easily manipulate with their paws or grip in their mouths. The treats were inaccessible to the dogs but clearly visible, and could of course also be readily detected by smell. The results were unambiguous. If there was only a single string, which led perpendicularly to a treat, the dogs could retrieve it immediately. But if the task was made at all complicated—for example by laying the string obliquely—the dogs tended to paw at the ground opposite the treat instead of approaching the block. At the first level of complexity, with layouts such as a single diagonal string, they quickly learned to correct this error; but with the most complex layout we used, where two

strings crossed each other, they showed no signs of learning within the limited number of trials we gave, and as Fig. 4b shows, they were frequently very far from a solution.

There are a number of reasons why dogs might fail in this task when other species succeed. It may be that the task is simply beyond dogs' intellectual capacities; this is the view that Osthaus et al. (2005) leaned towards. But it may be that there is something about the experimental situation that prevents dogs from deploying those capacities to the full extent—for example their ecological niche as a cursorial predator may have given them an overriding predisposition to approach prey directly when it is very close. For our present argument, however, what matters is not why the dogs failed, but the fact that they did fail, and what their failure tells us about the logic of the stimulus in this situation. For a human, it is appropriate to describe the strings as leading to or connected to the treats: we see them in that way, and respond by pulling the appropriate string without hesitation. For the dogs, evidently the dimension of connection is simply not there, at least initially; and though dogs can learn to use the strings, we have no means of knowing that they do so by coming to perceive the connection, or simply by learning a number of conditional operant discriminations.

Beyond stimulus logic

Stimuli come first, and if we are to understand animal cognition, we will have to understand the stimuli that we present to our animal subjects. The lesson of this paper is an obvious one: Humans, including human experimenters, “see” (and probably hear and feel) logical relations within stimuli that are not necessarily “there” for other species. Necessarily, the converse also holds. While the dog's inability to notice means-end relationships (at least in the experimental setup used by Osthaus et al. 2005) looks dysfunctional, the pigeon's concentration on local features of the visual stimulus is not necessarily a worse approach to parsing the stimulus, just a different one. Very possibly it reveals information that humans do not see, as Fujita and Ushitani (2005) indeed argued for the specific case of failure to complete occluded objects. And if we go back to raw perceptual capacities, of course the echo-location capacities of a dolphin or a bat give them a view of the world that we cannot share directly.

But even when other species share our view of the world, it does not follow that they can operate on it in the same way. In particular, the logic of the stimulus may constrain different species to different extents. Our human view of intelligence stresses, and prizes, its abstract nature. In Piaget's account of cognitive development in humans, the final stage is that of formal operations—where the child, or rather the young adult, becomes able to solve problems in an abstract, logical way,

regardless of the particular perceptual guise in which they present themselves. Despite Piaget's insistence (e.g. Piaget 1972) that this is a universal stage of cognitive development, the consistent evidence is that most human adults, most of the time, do not function at the formal operations level (e.g. Blasi and Hoeffel 1974). With difficult reasoning tasks, almost all humans are less likely to make errors if the task appears in a familiar concrete form (e.g. Wason and Shapiro 1971). If humans only manage to free ourselves from stimulus logic with difficulty, and in maturity, can we expect animals of any other species to achieve such independence at all?

But the fact that total independence of stimulus logic cannot be achieved does not mean that intelligence is totally stimulus bound. Danner and Day (1977) showed that even quite young children could, with appropriate help, show some formal operational thinking, and that the older the child, the easier it was to elicit such thinking. Similarly one might expect that independence of stimulus logic, while it will never be total, might be demonstrated to different extents in different species; though it would be a mistake to regard it as a measure of the overall "intelligence" of a species—only of the extent to which a species' intelligence is qualitatively similar to that of humans.

It is obvious that stimulus logic means that different species will be intelligent in different ways. But if this conclusion is obvious, it is less obvious what we can do about it. The idea of stimulus logic is grounded in Gestalt psychology, but the Gestalt approach does not offer a ready solution to the problems it poses. If sensory equipment and sensory analysis differ between taxa, the implication is that the Gestalt laws, and the Gestalten, cannot be the same for all species. If we want to know what our stimuli look like to our animal subjects, we shall have to find experimental ways of asking the animals themselves. Results like those discussed here create an urgent need for a wide-ranging comparative study of the logic of the stimulus and its role in animal cognition.

Acknowledgements This paper is based on one delivered at the symposium on animal logics held at the Konrad Lorenz Institute for Evolution and Cognition Research, Altenberg, Austria, in November 2004. The ideas presented here owe much to discussion with colleagues, notably Andy Wills, Alan Slater and Lucia Jacobs. Preparation of the manuscript was supported by European Communities Framework 6 (NEST) project 516542, "From Associations to Rules", and US National Institute of Mental Health grant MH068426. Kazuhiro Goto is now at Keio University.

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