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# Analogical Reasoning

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## Synonyms

Relational matching, relational thinking

## Definition

A process of reasoning based on a similitude of relations which is perceived between the objects compared.

## Introduction

Reasoning by analogy is one of the most complex forms of abstract thinking in humans. Consider the following analogy: the fish is to water what the bird is to air. To understand this analogy, one must first determine the relation between a first set of stimuli (i.e., the fish is *in* the water) and subsequently search for that same functional relation between the second set of stimuli (e.g., the bird is *in* the air). In other words, this two-step process therefore requires that we first appreciate first-order relations (the fish:water and bird:air relations), and subsequently compare and judge the relation between these relations (second-order relation). This form of inferential process based on analogical reasoning is fundamental for a diversity of cognitive processes of considerable importance in humans, such as classification, transfer of learning in new contexts, problem solving and creative thinking. The hypothesis has been repeatedly made that our exceptional abilities for analogical reasoning would be the major contributor to our high intelligence as a species (Hofstadter, 2001, Gentner, 2003).

One reason for which analogical reasoning is interesting is that it appears to be linked with human language. First, children with specific language impairment express difficulties in analogical tasks (Leroy, Parisse and Mallar, 2012). Second, although children already demonstrate rudiments of analogical reasoning at 2 years of age (Singer-Freeman, 2005), their performance in analogy tasks at 3-4 years of age is fostered by their emerging capacity to represent abstract relations via linguistic labeling (Christie and Gentner, 2014). Moreover, analogical reasoning does not approach adult-like performance until adolescence and the full growth of linguistic competencies (Richland, Morrison and Holyoak, 2006).

## Analogical reasoning in nonhuman animals

Comparative studies with nonhuman animals have questioned whether language is a prerequisite for complex forms of analogical reasoning. In this chapter, we will firstly document the fact that nonhuman animals have the capacity to process first-order relations. We will then document their ability for processing second-order relations, in other words, the relations between relations.

### ***Processing of first order relations in nonhuman animals***.

Many animal species can judge relations between things. For instance, baboons can be trained to indicate if one object is above or below another object (Dépy, Fagot and Vauclair, 1999). Particularly important for analogical reasoning is the abstract concept of sameness (identity). Using a wide variety of experimental tasks, researchers have shown that many animal species, including the chimpanzee, rhesus monkey, baboon, parrot, pigeon, rat, and even honeybee and bumblebee have sufficient cognitive power to indicate if two things are identical or different (see review in Wasserman, Castro and Fagot, 2017). In these experiments, the identity concept is presumed to be abstract, because the subjects express accurate same/different responses even when they must judge the relation between objects never seen before.

### *Processing of second-order relations in language or symbolic competent apes.*

Gillan, Premack, and Woodruff (1981) published the first paper on second-order relational processing in animals. These authors tested an enculturated language-trained chimpanzee (*Pan troglodytes*) named Sarah, who had already learned the symbolic meaning of pieces of plastic and could use and combine these symbols as words in sentences to communicate with the experimenter. In one first test condition, Sarah saw a tray containing one pair of objects on one side, and one single object on the other side. Two other objects were shown below the tray, and Sarah had to indicate which of these two objects would complement the single object on the tray, so that the relations entertained by these two objects is equivalent to the relations shown by the other stimulus pair. In another version of the task, Sarah was presented with two stimulus pairs, and she had to indicate if these two stimulus pairs showed the same or a different relation. She did so by selecting one piece of plastic symbolizing the same or different relations. Sarah was successful in these two versions of the task involving stimuli varying in shape, color, and marking. Moreover, she continued to be correct when the same tasks required the appreciation of functional relations between known household objects (e.g., closed lock and key vs. closed can and can opener). Considering Sarah’s initial training with symbols, Premack (1983) logically considered that Sarah’s success in the task of analogical reasoning can be explained by the cognitive competencies she developed via her “language” training.

The task used by Guillan et al. (1981) has never been replicated with other animal species. Later research on analogical reasoning in nonhuman animals has used instead the relational matching-to-sample task which is illustrated on the left side of Figure 1. In this task, the subject first perceives one pair of objects that are either identical or different. Two other pairs are then presented, and the subject must select the pair exemplifying the same (same or different) relation as the sample pair. One important feature of this task if that the items composing the sample are not used in the comparison pairs. Matching is therefore impossible of the sole basis of the individual items. Admittedly, the relational-matching-to-sample task captures several features of analogical reasoning, because it requires the apprehension of the relation between pairs of items (first-order relation), and also the processing of the relation between relations (second-order relation).

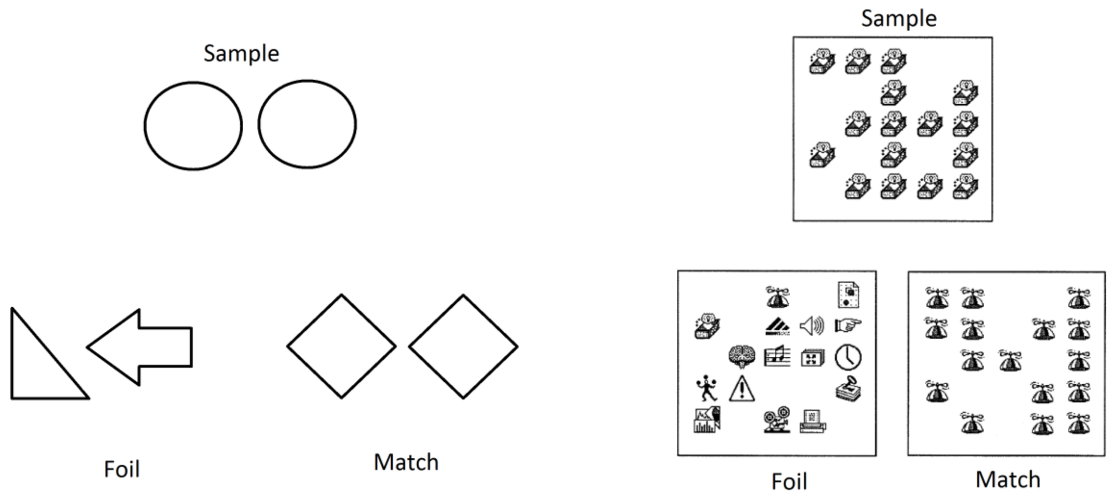


*Figure 1.* Illustration of two different versions of the relational matching-to-sample task. In both versions, the subject must indicate which of the two comparison stimuli (i.e., the match) instantiate the same relation as the sample stimuli. In the left-most version, the same different/ relations are illustrated by pairs of stimuli. In the right-most version of the task, the same/different relations are shown by arrays of icons.

Premack’s (1983) conclusion that language training is required for analogical reasoning was questioned by Thompson, Oden and Boysen (1997). These authors tested five chimpanzees on a version of the relational matching-to-sample task using pairs of real objects or digitized images. One of the subjects was the language-trained chimpanzee Sarah cited above. Three other chimpanzees were language naïve, but these subjects had previously learned the meaning of two different token shapes, each symbolizing the same or different relation. The last chimpanzee was both language- and symbol-naïve. Sarah and the three token-trained chimpanzees could successfully solve the relational matching-to-sample task, with no reliable difference among them. By contrast, the last chimpanzee who was both language and token-naïve failed miserably in the task. From their results, Thompson et al. (1997) concluded that the ability to process the relation between relations requires at least a form of symbolic/token training. This conclusion was however premature, as shown below.

***Processing of second-order relations in language-naïve primates and birds***.

Most of the initial attempts to present the relational matching-to-sample task to language- or token-naïve animals were failures (see review in Thompson and Oden, 1996, 2000). However, the picture began to change when researchers reasoned that relational matching could be facilitated if the relations are shown in arrays of multiple stimuli, rather than same/different stimulus pairs. Following this reasoning, Fagot, Wasserman and Young (2001) trained two Guinea baboons (*Papio papio*) in a version of the relational matching task using arrays of 16 (same or different) icons as sample and comparison stimuli. Figure 1 (right side) illustrates the kind of displays used in this task. The two baboons tested in Fagot et al. (2001) could achieve a high level of performance during the training phase. After training, they even continued to be above chance when a new set of icons was used to create each array, suggesting an ability to match relations between relations. The success of the baboons with arrays of icons prompted Cook and Wasserman (2007) to replicate that procedure with pigeons (*Columba livia*). These authors found that the birds could achieve 70% correct at the end of the training period. Much like baboons, the pigeons could also transfer their performance to new sets of stimuli. These findings were the first demonstrations that monkeys and pigeons have the capacity to match relations between relations.

A different approach to the problem was to capitalize on potential benefits of extensive training in the relational matching task. This procedural strategy was possible thanks to the most recent technological developments allowing the animals to be tested via an automated identification, with no need to remove them from their social group. Fagot and Thompson (2011) used this procedure with a group of 29 Guinea baboons (*Papio papio*) tested with a version of the relational matching to sample task shown on the left of Figure 1. Most of the baboons failed to learn the task, but five of them did. These five individuals could moreover maintain a high level of performance with stimuli never seen before. The fact that nonhuman primates can learn the relational matching-to-sample task with pairs of items is further confirmed in one capuchin (*Cebus apella*), among five, by Truppa, Piano Mortari, Garofoli, Privitera and Visalberghi (2011). The training phase required approximately 17,000 trials in this study on capuchins, which is in the same range as for baboons (Fagot et al., 2011).

In a more recent project, Smirnova, Zorina, Obozova, and Wasserman (2015) tested two hooded crows (*Corvus cornix*) which had already been trained on the identity concept. This study used pairs of shapes drawn on carton boards as stimuli in the relational matching-to-sample task. To obtain a bait, the crows had to lift the carton board showing the same relation as the sample board. The crows readily displayed high levels of relational responding in this task, and they did so in several versions of the task requiring an appreciation of the relations expressed by stimulus size, shape, and color. The authors explained this astonishing performance by the initial training that the birds have received on the identity concept. An earlier study on language-naïve orangutans (*Pongo pygmeus*) and gorilla (*Gorilla gorilla*) had already shown that these animals can achieve a high level of performance in the relational-matching-task without extensive training (Vonk, 2003).

**Are there alternative explanations to relational responding**?

The possibility that nonhuman animals have sufficient cognitive capacities for second-order relational thinking remains a matter of hot debate, and researchers have examined alternative explanations that could explain their behavior in the relational matching-to-sample task. Penn, Holyoak and Povinelli (2008) proposed that the nonhuman animals consider for responding the entropy of the displays in the relational matching-to-sample task, rather than the relations among the items present in the displays. The concept of entropy has been introduced in this literature by Young and Wasserman (1997), and it corresponds to the degree of perceptual variability between the elements contained in each display. Following Penn et al.'s idea, the subjects would consider that an array containing different icons is more variable than an array containing identical items. This type of encoding would allow the matching of same or different arrays in the relational matching task on the sole basis of a global apprehension of the perceptual variability of the sample and comparison displays, rather than their relational properties. This hypothesis was directly tested by Flemming, Thompson and Fagot (2013). Using arrays of icons containing only 4 items, they manipulated the entropy of the sample independently of their relation. They used sample stimuli which had the following possible structures: AAAA (all same icons, entropy = 0), AAAB (entropy = 0.81), AABB(entropy = 1.0) and AABC (entropy = 1.5), ABCD (all different icons, entropy=2), with the location of each item randomized across trials.. In a comparative perspective, these authors have also tested humans and baboons in this task. In the two species, results indicated that the relational structure of the sample arrays was the primary variable controlling subjects' choice performance. An effect of entropy was also revealed by the results, in both humans and baboons, but in both species this effect was secondarily to the effect of the relations. This result is an additional confirmation that nonhuman animal species have the capacity to solve the relational matching task, and that their performance is controlled by the relational structure displays.

**Conclusions**

Analogical reasoning is considered a hallmark of higher-order reasoning, and recent theoretical perspectives assert that this is a uniquely human cognitive trait (Penn et al., 2008). The close relationship found between the development of analogical reasoning and the emergence of language competence in children supports the conclusion that a linguistic mode of encoding is needed for the emergence of complex forms of relational thinking. An initial study in a language-trained chimpanzee has supported this conclusion (Gillan et al., 1981; Premack, 1983). However, more recent attempts to investigate the extent and limits of relational thinking in linguistic naïve animals have shown that several species, including the pigeon, capuchin, baboon, chimpanzee, gorilla and orangutan can demonstrate second-order relational processing in the relational matching task (for an extensive review of this literature, see Wasserman et al., 2017). All these findings demonstrate that linguistic competences are not necessary for complex relational thinking, although a linguistic encoding of the task might of course help (e.g., Christie and Gentner, 2013). One obvious limitation of this literature is that it probably focuses too much on the relational matching-to-sample task. Admittedly, this task cannot capture the full complexity of the processes involved in analogical thinking in humans, for instance when we solve verbal analogies as complex as the well-known analogy which compares the solar system to the *Rutherford* atom model. The relational matching-to-sample task nevertheless contains some of the most basic features of analogical reasoning, among them the fact that the subjects must associate relation between relations. A close examination of the current comparative data suggests that nonhuman animals possess at least some of the cognitive antecedents of analogical reasoning in humans.

Cross-references: causal reasoning, David Premack, inductive reasoning, matching to sample, means-end reasoning,

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