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Learning *same* and *different* relations: cross-species comparisons

Dedre Gentner[1], Ruxue Shao[1], Nina Simms[2] and Susan Hespos[1]

Humans excel among species in abstract representation and reasoning. We argue that the ability to learn through analogical comparison, augmented by symbolic systems, underlies our cognitive advantage. The relations *same* and *different* are an ideal testbed for these ideas: they are fundamental, essential to abstract combinatorial thought, perceptually available, and studied extensively across species. The evidence suggests that whereas a sense of similarity is widely shared across species, abstract representations of *same* and *different* are not. We make three key claims, First, analogical comparison is critical in enabling relational learning among humans. Second, relational symbols support forming and retaining *same* and *different* relations in both humans and chimpanzees. Third, despite differences in degree of relational ability, humans and chimpanzees show significant parallels in the development of relational insight.

Addresses
[1] Psychology Department, Northwestern University, United States
[2] Spatial Intelligence and Learning Center, Northwestern University, United States

Corresponding author: Gentner, Dedre (gentner@northwestern.edu)

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Humans stand out among other species in having exceptional talent for relational representation and reasoning, and this ability is a major contributor to our cognitive prowess [1–4]. Contrary to some accounts [4], comparative studies have made it clear that our closest relatives, chimpanzees and bonobos, have some degree of analogical ability [5,6•]. For example, in a spatial mapping task, three-year-old children and the two Pan species (chimpanzees and bonobos) showed sensitivity to matching relational patterns, while orangutans did not. However, the three-year-olds were considerably more sensitive to relational similarity than were the Pan species [5].

How do we come by this powerful relational ability? One possibility is that humans begin life endowed with a core set of relations, which we can combine to create our repertoire of relational representations [7,8]. One appeal of this proposal is that it is otherwise hard to imagine how abstract relations could come about. Here we argue that abstract relations can be learned. We maintain that humans are endowed with powerful structure-mapping processes [1,2] that enable us to learn abstract relations from experience. We make two main claims. First, relations can be abstracted via analogical comparison. Second, language supports analogical learning in several crucial ways.

The relations *same* and *different* are the ideal arena in which to address these questions. First, these relations are central to concept formation and to abstract combinatorial thought. Second, they are arguably among the most fundamental relations, and are therefore top candidates for inclusion in a set of innate relations. Third, sameness is perceptually salient, and might therefore be privileged in early learning. Finally, *same–different* relations have been studied extensively across species, offering the possibility of phylogenetic as well as ontogenetic comparisons.

We first briefly review evidence for two key supports for relational learning in humans: analogical comparison and language. Then we discuss research on *same* and *different* in other primates and discuss parallels and differences with studies of young humans.

Analogical comparison

By analogical comparison, we mean a *structure-mapping* process in which the relational structure of the two items is aligned, rendering their common relational structure more salient [2,9,10]. Two key signatures of the structure-mapping process are that (1) comparing and aligning different examples promotes noticing and abstracting the common relational pattern; and (2) attention to individual objects undermines relational abstraction [10–12]. The ability to carry out structural alignment across a series of examples is present even in the first year of life [13,14]. By seven-months, infants who are habituated to a series of pairs instantiating the *same* relation will then look longer at a new *different* pair than at a new *same* pair—evidence that they abstracted the *same* relation during habituation [13]. The reverse pattern holds for infants habituated to *different* pairs. Even three-month-olds show signatures of structural alignment and abstraction, although with limitations [14]. (See Hespos *et al.*, this issue, for details.). Of course, these abstractions may be more concrete than the adult concepts of *same* and *different*, as discussed below, and may not be retained beyond the immediate task. Nonetheless, these findings suggest that the ability to abstract relations via analogical comparison is present in very young infant[3] .

Language

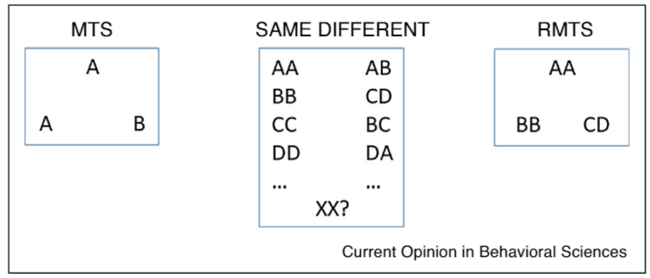
The preceding discussion shows that infants can carry out structural alignment and abstraction before acquiring language. However, once acquired, language supports human relational learning and reasoning in several ways [1,2,15,16]. First, having a symbolic label for a concept supports the ability to notice and use that concept, in children [11,12,23,24,15–19,20•,21,22] and adults [25,26•,27,28•]. Second, using a common label for two items prompts children to compare them, allowing them to notice and retain their commonalities [10,11,24,29•]. Third, a set of related words can invite what Carey [30,31] called 'Quinian bootstrapping', whereby even before understanding the full meanings of the words, children form a placeholder structure that supports learning the full relational system. Finally, once learned, relational language can foster attention to larger relational patterns [16,19,30–32].

Comparative research on *same* and *different*

Paradigms that aim to capture *same–different* ability have a long history in the comparative literature and have led to new perspectives on human learning and development. One line of investigation stems from the research of Premack *et al.* In Premack's [33] seminal paper on similarity, he distinguished three tasks that all seem to tap into the perception of *same* and *different* (Figure 1), but that are in fact vastly different in their profiles. The easiest of these is the object match-to-sample task (MTS; Given A, choose A over B). The MTS task can be passed by many species, including pigeons, macaques and honeybees, [34,35•,36–39]. Among humans, the MTS can be passed by human infants as young as 10 months [40,41].

The second task Premack discussed is the *same–different* task. Here the subject is taught to give one response for instances of *same* (AA, BB, CC, etc.) and a different response for instances of *different* (AB, CD, BC etc.). If, after mastering the training set, the subject can correctly categorize new examples (XX versus YZ), they are credited with having passed the *same–different* task. The *same–different* task is more demanding than the MTS task. Many species that can master the MTS task cannot pass the *same–different* task. For example, pigeons can pass MTS, but not the 2-item *same–different* task [38].

Figure 1



Premack's Three Tasks. In MTS (Match-to-Sample), the subject must choose the alternative that matches the standard. In *same–different,* the subject learns to make distinctive responses for a set of *same* pairs versus a set of *different* pairs, and then must respond to a novel pair. In RMTS (Relational Match-to-Sample), the subject must choose the alternative whose relation matches that of the standard.

Thus one important insight from Premack's analysis is that the act of matching two identical objects (say, X with X) does not entail forming the relation *same* (X,X). That is, success on the MTS can be carried by perceiving a match—perhaps simply by a strong sensation of similarity—rather than by representing the relation *same* [20•]. In contrast, the *same–different* task requires the ability to classify individual pairs of items as depicting *same* or *different* relations.

To test whether a subject has truly formed a relational representation of *same* (or *different*), Premack invented the Relational-Match-to-Sample task (RTMS)—a task that has become a classic test of relational ability. The RMTS task (Given AA, choose XX over YZ; given BC, choose YZ over XX) is far more challenging than the previous two tasks. It requires encoding the relation between each pair of objects and choosing the alternative that shares a relation with the standard. Passing the RMTS task is clear evidence of possessing representations of *same* and *different* that can be retrieved, applied across distinct stimuli, and considered simultaneously to find a match. Just as the set of successful species dwindles as we move from MTS to *same–different*, so the set becomes smaller still when we move to the RMTS[4] . For example, Flemming *et al.* [35•] successfully taught rhesus macaques to pass a *same–different* task. But when these monkeys[5] went

[3] On each trial, the pair of objects moved together in an eight-second pattern. This was repeated for up to a minute; then the next pair was shown, with the same pattern of motion. Thus the infants had multiple opportunities to align within and across trials. Immediately after the learning trials, infants saw six test trials, alternating between *same* and *different*; their looking time to each test trial was the key measure.

[4] Our focus here is chiefly on primates. However, recent studies have found that two hooded crows [55] and also two parrots [56] have passed the RMTS after extensive training on other kinds of matching tasks. This intriguing work is consistent with other evidence that corvids and psittacine birds may be exceptionally intelligent [57,58].

[5] Baboons have also passed the RMTS task. However, only 6 of the 28 baboons tested reached the criterion of 80% correct, and only after 15 400–32 100 trials [34].

on to the RMTS, none of them performed above chance, even after over 10 000 trials.

In Premack's [33] research on the RMTS, the subject was Sarah, a chimpanzee who had received extensive training in a language-like system that used plastic chips as symbols—among them two chips that symbolized *same* and *different*. In addition to passing other analogy tasks, Sarah was 100% correct on the RMTS task. In contrast, four chimpanzees similarly reared by humans, but not taught symbols, were at chance even after 15 session of 12 trials each, with corrective feedback. This led Premack [33,42] to propose a major role for language: namely, that language enables an abstract code that permits representing abstract relations. Equipped with symbols for relations, the subject can encode (for example) XX as *same* (X,X) and likewise for the other relations, and thereby perceive that XX matches AA rather than BC, as required for the RMTS task. Further evidence for the beneficial effect of symbols comes from a study by Thompson *et al.* [37]. They tested five chimpanzees on the RMTS task, four of whom had received prior training with symbols for *same* and *different* pairs (among them, Sarah). These four passed the RMTS in as few as 32 and at most 96 trials. The fifth chimpanzee, who had not been trained with *same*/*different* symbols, failed to reach the 75% correct criterion within 128 trials.

The comparative literature thus reveals a gradient of difficulty among similarity tasks, reflecting increasing representational demands for *same* (and *different*). Further, symbolic knowledge supports performance on the most challenging of those tasks, the RMTS, in our close relatives, chimpanzees.

Developmental research on *same* and *different*

If humans are endowed with representations of *same* and *different*, they should not show such a gradient. Yet the evidence suggests that they do. The MTS can be passed by human infants at 10 months [40,41], but 2-year-olds do not pass the standard *same–different* task [24]. Success on the RMTS occurs still later—not until four years of age [24]. Christie and Gentner [24] gave children a *same*-only version of the RMTS task. Children were given eight RMTS trials, all with a *same* relation as standard, with no practice nor feedback. Although four-year-olds passed, two-year-olds and three-year-olds failed. In subsequent studies, Shao, Simms and Gentner (in preparation) have generalized these findings. Using the same methods as in Ref. [24] (eight RMTS trials, with no practice nor feedback), they have found that four-year-olds can pass the full RMTS task (i.e. four *same* and four *different* trials).

In an intriguing parallel with chimpanzees, young children benefit from learning symbols for *same* and *different*. Christie and Gentner [24] taught three-year-olds to label pairs as *same* or *different*, and then gave them the same-only RMTS task.[6] With this training, three-year-olds readily passed the RMTS task. Two-year-olds received the same training, but only 46% succeeded in labeling the pairs even after 24 trials. That is, unlike three-year-olds, two-year-olds could not pass a *same–different* task (the training) or the RMTS.

Other studies have also found evidence for the role of *same–different* labels in supporting these relational concepts. Hochmann *et al.* [20•] examined the justifications children gave for their choices in the RMTS task and found that of the (mostly five-year-old) children who succeeded on the RMTS in their lab, 88% used the words *same* and/or *different* (or an equivalent phrase) in explaining their choices. None of the non-succeeders did. Shao *et al.* (in prep) found a similar pattern among four-year-olds: children who used *same*/*different* in their justifications were more accurate on the RMTS than those who did not.

Thus, Premack's gradient among sameness tasks is manifest in ontogeny as well as phylogeny. But what drives this gradient? As suggested above, the MTS task requires only that the subject choose the alternative that elicits a greater sense of similarity; it does not require forming a *same* or *different* relation. The *same–different* task sets a higher bar: the subject must be able to identify sameness (or its lack) when given an individual pair. Ability to pass the *same–different* task may be a prerequisite for passing the RMTS task, but it is not sufficient. To succeed on the RMTS task requires that the subject readily encode the standard and the correct choice in the same way, and the incorrect choice in a different way. For this to happen, the subject must have *same* and *different* relations that are sufficiently established as to be readily accessible across different contexts. Developmental evidence suggests that one advantage of symbols is that they promote stable, accessible representations [11,12,23,24,15–22].

Array matching

The research discussed so far has focused on *same–different* relations over binary pairs. Other comparative research has focused on the ability to distinguish sameness and difference using arrays of, for example, 16 items [43,44]. These tasks differ markedly from the ones discussed so far in that they can be passed by species such as pigeons and macaques that typically fail the two-item *same–different* task. As Wasserman and Young [38] review, the animals' behavior in these large array tasks appears to be controlled by the perception of entropy (i.e. the variability of items within an array). Entropy is a global property of an array. Thus, matching two arrays does not require perceiving a match between two relations; rather,

[6] The labeling task used different materials than the subsequent RMTS task, and children were not told that the two tasks were connected, nor were they encouraged to use labels during the RMTS task.

it requires perceiving a match between properties of the arrays (i.e. that the variability in Array 1 is the same as that in Array 2). In contrast, to pass the 2-item *same–different* task requires learning and discriminating between relations, and reflects a qualitatively different ability than is tapped by the array tasks [45].

Young children also find array matches easy. Hochmann *et al.* [20•] found that three-year-old children readily passed an Array-MTS task, but could not pass the standard RMTS task. It appears that humans, like other species, can perceive and use relative entropy without the aid of symbols. But unlike most other species, humans (and chimpanzees to some extent) can derive relational abstractions via analogical comparison and, given symbols, can retain and reuse those relational representations.

Discussion

The above review raises further issues. First, given the importance of comparison and alignment in relational learning, it's important to ask what leads children to spontaneously compare things (that is, to compare without being asked to). Spontaneous comparison is fostered by high similarity and close spatial alignment [2,22,46]. Another spur to comparison is hearing the same label applied to two things; common labels invite comparison [11,47]. Curiosity can also spark comparison. For example, in Walker and Gopnik's [48] task, a two-year-old is asked to predict what makes a music box play. The child watches as a series of *same* or *different* pairs is put on the machine: for example, AA (music); AA (music), BC (no music), BC (no music), DD (music), DD (music), EF (no music), EF (no music). After this experience, children largely succeed in choosing which new pair will make the music box play. The sequential juxtaposition of comparable pairs, together with children's intrinsic interest in causal patterns [48] leads children to compare across trials and arrive at a *same* (or *different*) abstraction.

Second, how should we characterize infants' relational abstractions in our studies? We think it likely that their representations were more concrete and contextually bound than adult representations of these concepts [46]. For example, Kotovsky and Gentner [12] found that four-year-olds given a simple perceptual similarity task could correctly match two symmetric patterns when the symmetry was expressed along the same dimension, but not when the dimensions differed—for example, given a *small, big, small* pattern (compose of pink circles), they could match it with *small, big, small*, but not with *light, dark, light* (both composed of blue squares). However, receiving sets of readily alignable same-dimension trials allowed children to abstract their notion of symmetry to apply across dimensions as well as within-dimension [49].

Third, how is it that prelinguistic infants can abstract *same* and *different* [13,14], yet four-year-olds fail the RMTS task [24]? Part of the answer lies in differing task demands: the RMTS task requires the child to produce an explicit response, whereas the infants only had to look at the stimuli, with length of looking as the dependent measure. Beyond this, whereas the RMTS task requires a response after each example, the infants were given a set of learning trials followed by a set of test trials. In the learning trials, infants saw a series of (for example) *same* pairs until their looking time declined across trials (i.e. a habituation criterion ranging from 6 to 9 trials). As noted earlier, within each trial, the pair moved in the same repeated motion pattern. We suggest that this, together with the close temporal juxtaposition of pairs, engaged a spontaneous comparison process that lead to alignment and gradual abstraction of the common relation. The six test trials—half depicting *same*, half *different*—came immediately after the learning trials; the key measure was whether they looked longer at trials depicting the novel relation. In short, the infants were given a learning sequence, whereas the older children were asked to apply what they already knew. This view of the habituation sequence fits with evidence that habituation and familiarization can lead to relational learning (e.g. Refs. [50–52]) and that structure-sensitive abstraction can occur without conscious intent [53].

This pattern has a parallel in chimpanzees. Oden *et al.* [54] allowed infant chimpanzees to play with a pair of *same* toys, and then gave them a new pair. The infant chimpanzees spent longer when given a new *different* pair than when given a new *same* pair (and the reverse when the initial pair was two *different* toys). However, these same animals, and even adult chimpanzees lacking symbol training, fail on the RMTS task. Thus, we see an analogous pattern of (a) early ability to abstract relations in an implicit task, (b) failure on the RMTS task; and (c) the ability to learn symbolic relational representations that support retaining the concept and using it in the RMTS.

Conclusions

We make three main points. First, analogical comparison and abstraction are critical in learning and using relational representations, and are therefore central to higher-order cognition. Second, symbol systems such as language are necessary in order to realize the full potential of our relational ability. Finally, although humans are paragons of relational ability, there are many parallels in relational development between humans and chimpanzees. These parallels can give us insight about the evolution and development of human cognition.

Conflict of interest statement

Nothing declared.

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This paper compared three-year-olds' performance on a spatial mapping task to the performance of three non-human great apes (bonobos, chimpanzees, and orangutans). The first study showed that three-year-old humans, chimpanzees and bonobos were able to take advantage of a spatial analogy to gain reinforcement. The second study showed although children were highly sensitive to object similarity, nonhuman apes were not. The authors speculate young children's sensitivity to object similarity may be increased by early language-learning, which is often focused on object names.

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In a series of studies, three-year-olds to five-year-olds were given Array MTS (AMTS) and 2-item RMTS tasks. Two key findings point to the role of language in children's relational matching. First, five-year-olds who were successful on the RMTS were likely to justify their choices using *same/different* language. Second, although all three-year-olds relied on entropy to match on the AMTS, as many non-human animals do, some four-year-olds made categorical all-same versus not-all-same discriminations, as human adults do. These children were more likely than the other four-year-olds to use *same/different* language in their justifications, *and* to succeed on a subsequent RMTS.

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Nicaraguan Sign Language (NSL) is an evolving sign language formed as deaf people in Nicaragua came together in a school and worked out a common gestural system. As succeeding cohorts of students arrived, they learned the existing system and added syntactic and semantic devices for expressing meaning. The authors found that adult speakers from a later cohort had more consistent spatial language than those from an early cohort. They further found that command of specific spatial language was correlated with performance on two nonlinguistic spatial tasks—suggesting a strong relation between spatial language and spatial cognition.

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