Learning sameness: object and relational similarity across species

Article *in* Current Opinion in Behavioral Sciences · February 2021

DOI: 10.1016/j.cobeha.2020.06.010

Stella Christie
Tsinghua University
18 PUBLICATIONS **362** CITATIONS

Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Behavioral Sciences

Learning sameness: object and relational similarity across species

Stella Christie

Humans' impressive cognitive abilities — map reading, understanding numerical structure, learning grammar rules — rest on the ability to abstract sameness of relations. How does this ability arise and why do animals not read maps or learn grammars like humans do? Here, I review evidence suggesting that object similarity — perceiving that two events look alike — is crucial for *learning* to perceive relational similarity. While both humans and nonhuman animals perceive object similarity, species differ in their initial preference for objects relative to relations and in their learning trajectories. Human children spontaneously prefer object over relational similarity and this preference benefits their relational reasoning; animals do not favor object similarity. For animals, relational abstraction is easier when the underlying objects are dissimilar, but in humans this relationship is concave.

Address
Tsinghua Laboratory of Brain and Intelligence and Department of Psychology, Tsinghua University, China

Corresponding author: Christie, Stella (christie@tsinghua.edu.cn)

Current Opinion in Behavioral Sciences 2020, **37**:41–46

This review comes from a themed issue on **Same-different conceptualization**

Edited by **Edward A Wasserman**, **Jean-Rémy Hochmann** and **Susan Carey**

https://doi.org/10.1016/j.cobeha.2020.06.010

In a classic study by Chi, Feltovich, and Gasser [1] novice and expert physicists (undergraduate physics majors and physics graduate students) were asked to classify textbook physics problems. The two groups differed markedly in their classifications: the novices grouped together problems that involved the same physical properties — such as questions that involved inclined planes — while the experts grouped together problems that exploited the same physics principles — for example, problems whose solutions relied on conservation of angular momentum. Both groups used *sameness*, but of a different nature: the novices focused on perceptual sameness — *object similarity* — while the experts focused on *relational similarity*.

The ability to perceive object versus relational similarity critically impacts reasoning. In the Chi, Feltovich, and Gasser [1] study, the experts' relational abstraction would allow them to solve problems accurately and efficiently, with many seemingly different questions unlocked by the same principle. By contrast, the novices' focus on object similarity hindered their problem solving: in insisting that two problems which contained inclined planes were similar, the novices would overlook their optimal solutions.

The capacity to perceive relational similarity is necessary for abstract, relational higher order-thinking [2,3•] and is often argued to be the distinguishing feature of human cognition [4]. However, in studying our sensitivity to relational similarity one must be mindful of its apparent rival — object similarity. Here, I review evidence from developmental (humans) and comparative studies to establish three assertions. The first one concerns the dual role of object similarity in relational abstraction: focus on object similarity can both hinder and help learners to perceive relational similarity. Second, humans and apes differ in their initial focus on object versus relational similarity. Third, the relative saliency of object versus relational similarity changes across development and the pattern of change differs between humans and animals.

Object similarity hinders and helps relational reasoning

When young children face a choice between an object match and a relational match, they often find the former more salient. For example, in study [5] four-year-olds were shown a standard containing two identical objects AA (e.g. two circles) and two choices: a Relational Match card containing identical objects BB (e.g. two triangles) or an Object Match card AC (e.g. a circle and a cross; the circle here matches the circle in the standard card). Given these choices, children strongly preferred the AC (object match) over the BB (relational match) as the match to the standard AA. The preference for object similarity is a robust finding in developmental studies that pit object against relational matches [6•], with similar results reported in number tasks [7], verb learning [8], scene analogies [9] and spatial mapping tasks [10]. The scene analogy task in [9] required children to match characters based on the roles they played in the scenes, but — as an example — children typically mapped cat the chaser to a bystander cat rather than to boy the chaser. In the spatial mapping study [10] three-year-olds were given a map to find a hidden treasure in a room. They succeeded when the map and the room matched exactly, but a conflicting object — such as a chair in the middle of the map and on one side of the room — would throw them off. The object match was a more salient cue to finding the treasure than were the spatial relations.

Maps provide a good illustration of the tradeoff between object and relational similarities. Reading a map is in essence a relational task: one needs to match relations between map ideograms to relations in physical space. When a chair was displayed where it did not belong, three-year-olds organized their search around the mislabeled chair, not according to the correctly portrayed relations. The adult readers of this review can probably empathize with the child subjects by contemplating how confusing a map of New York would be if it showed a picture of the Empire State Building jutting out from the residential neighborhoods of Queens. The key point is not that the map user is incapable of perceiving relational similarity but that the saliency of object similarity can easily detract one's relational reasoning.

Precisely because object similarity is available and salient in the minds of novice learners, it can bootstrap perception of relational similarity [11,12]. The saliency of perceptual similitude invites learners to *compare* and align, thereby highlighting common relational structure [13]. A hallmark example is the Relational Match to Sample Task (RMTS): given standard AA, choose between BB and CD. Two-year-olds performed at random in this test, except if they were first trained with 'easy similarity' triads, where the relational matches were also object matches: given AA, choose between AA and CD) [14]. The finding cannot be attributed to sheer training because children still performed at random during the RMTS test when they were trained with the actual test triads. A similar benefit of object similarity has been found in three-month-old infants [15•]. Those habituated with diverse pairs instantiating the relation *same* (e.g. AA, BB, CC . . .) failed to abstract the relation to novel pairs XX; the infants habituated with two alternating pairs (AA, BB, AA, BB . . .) succeeded in the generalization. A potential explanation is that the alternating pattern rendered similarities across exemplars salient, inviting *comparison*, which in turn highlighted the relational similarity. While in theory diverse pairs (AA, BB, CC,..) could also be compared, their multitude likely made the comparison more difficult and obscured their similarity. The mechanism whereby children build up on object similarity to arrive at relational abstraction has been seen in multiple domains and paradigms, from spatial tasks [10] to language learning [16] to number tasks [17,18•].

How object similarity affects relational abstraction depends on the way the similar objects are deployed. When they occupy relationally matching roles, their effect is to highlight the common relation. In contrast, similar objects occupying relationally discrepant roles detract and dampen learners' ability to perceive relational similarity. These regularities proclaim an important conclusion: that the capacity to perceive relational similarity can be *learned*, and that focus on object similarity is an early accessible tool for relational learning.

Initial state of object and relational similarity

The assertion that relational abstraction is learned — and that the learning benefits from recognizing object similarities — poses several questions concerning the preference for object matches. Do all learners benefit from object similarity en route to becoming relational thinkers? If they do, is preference for object similarity acquired or preconfigured? For this, we will examine both humans and nonhuman animals.

In human studies, direct evidence for early sensitivity to object matches is limited but indirect evidence is plentiful. Newborns show a specific and unique brain activation in the superior temporal and left inferior frontal regions when they hear patterns that consist of repeating elements. This activation does not occur when equally complex patterns without repeating elements are played [19]. These findings give direct evidence that noticing object similarity — that A is identical to A — is available very early on. There is also indirect evidence. The paradigm of most infant studies, in which habituation events precede test trials, presumes a preference for objects in that similar-looking objects or events portray the tested concept during habituation in the hope of making the concept more accessible. In this way, a big part of the literature on early development tacitly assumes that the route to relations is via objects, to which we attend preferentially by default. An illustrative example is Quinn's study, which tested three-month-olds' knowledge of *above* and *below* [20]. Infants responded to these spatial relational concepts after habituation runs involving diamonds at various distances above and below a line, but not when habituation was carried out with diverse objects such as dots, arrows, or triangles [21]. We have already discussed the similar results of study [15•]: three-month-old infants could abstract the relational concepts *same* and *different* after habituation events featuring two alternating pairs thrice, but not after seeing six different pairs. The common theme of these works is that infants were able to grasp relations because they first matched objects — an ability they wielded without overt training.

That nonhuman animals readily perceive object similarity is a well-established claim. The largest body of evidence comes from match-to-sample (MTS) studies, where the animal is given a sample stimulus and has to match one of two alternatives using physical similarity (given A, match A not B). After training with two objects, subjects are asked to generalize the matching to new items. Many species succeed in this task, including pigeons [22], Old and New World monkeys [23], chimpanzees [24], and crows [25]. Chimpanzees stand out in that they, like humans, can discriminate based on object matches already in infancy: in Oden, Thompson, and Premack's study, infant chimpanzees passed an MTS task [26].

Although both humans and nonhuman animals can identify object matches, they differ in their attention to object similarity relative to other types of similarities. As we discussed, human children strongly and robustly prefer object similarity over relational similarity, the same preference observed in multiple domains and tasks [3•,14]. There is, of course, some variation. Children in Japan and China have been reported to show a weaker preference for object matches than their American peers [27,28•,6•], although those studies did not directly pit object against relational similarity. A case in point is Carstensen *et al.'s* work [28•], in which two-year-old and three-year-old Chinese children generalized the relational rule *different* (used to activate a novel machine) to a choice containing *both* the relational and the object match while American children chose the option that only contained object matches. By and large, though, the early spontaneous preference of human children for object matches is a robust and well-documented phenomenon.

Surprisingly, this preference is *not* shared with nonhuman animals. Fagot and Thompson [29] tested naïve (no prior symbol training) baboons in a standard RMTS task with identity and non-identity relations. Six of the 26 baboons that reached training criteria could generalize their relational matching to novel stimuli. When these baboons were subsequently tested on an RMTS task that pitted object against relational similarity (e.g. sample AA; choices BB and AC), they persisted in selecting the relational match. An almost identical paradigm with three-year-old and four-year-old human children yielded the opposite result [5]. Similar to baboons, chimpanzees and bonobos also do not prefer object similarity over relational similarity [30]. In this study, great apes and three-year-old children did an identical spatial mapping task: mapping spaces either based on spatial relations (top to top, middle to middle, bottom to bottom) or based on object matches that conflicted with the spatial relations (e.g. mapping a red container at top to a red container at bottom). Human children strongly preferred object similarity but chimpanzees and bonobos did not.

To my knowledge, these are the only two comparative studies that directly pit object against relational similarities. While the results are somewhat surprising, they consistently point to animals not strongly preferring object over relational similarities. We need more studies in the future to see if this relative non-preference holds in other species. If this absence of object bias holds, however, it may have a large effect on relational reasoning. While in the short run non-human animals are less distracted by object matches (compared to human children), in the long run this absence of object bias diminishes the opportunity to compare and learn relational abstraction.

Changes in preference for object versus relational similarity

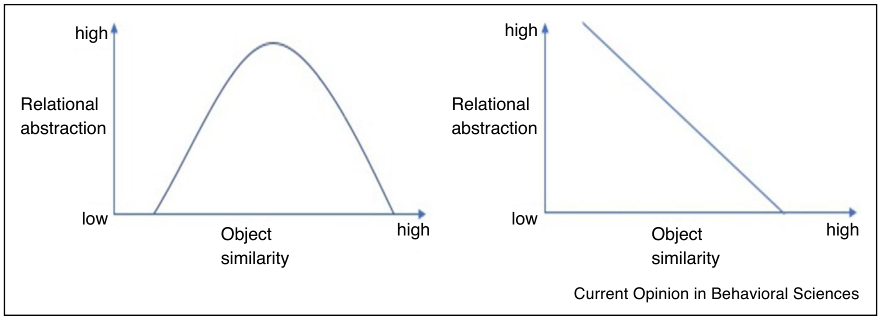
Humans' early spontaneous preference for object over relational similarity is reversed later on in development. For example, while four-year-olds preferred to match based on object similarity in the RMTS task, a majority of adults in the same study spontaneously preferred the relational similarity option [5]. Likewise, in a scene analogy task, four-year-olds could not find the relational match because they were distracted by competing object matches while six-year-olds were less impacted by the presence of object similarity [9].

Why (and when) the spontaneous preference for object matches gives way to a preference for relations has been the subject of an extensive debate; the proposed answers include language development, changes in domain knowledge, or maturation in executive function [31–33,7]. That discussion is, for the most part, immaterial to a cross-species analysis because all the aforementioned factors are limited or altogether absent in nonhuman animals. One vector of change, however, is theoretically available to all species — it is the variability of objects, or how similar they are in their perceptual features. Is it easier to perceive relational similarity when the underlying objects are less similar on the surface?

Among nonhuman animals, a preliminary answer is yes [34]. For example, pigeons learned horizontal and vertical relational patterns after they were trained with 64 different items but not with 16 items or fewer [35], with a similar effect reported in baboons [36] and rats [37•]. Animals seem to face a direct tradeoff between variability and object focus: the greater the variability of the training items, the less attention animals commit to the identity of the objects, which affords a better focus on relations [38].

That tradeoff is not apparent in young children's relational reasoning. In an infant analogy study three-month-olds successfully learned relations after being habituated to two alternating pairs, but not to six distinct pairs [15•, see also Ref. 39] — a decline in relational abstraction due to the greater variability of objects. We saw earlier that a similar conclusion was reached in [14], where two-year-olds failed an RMTS task unless the training involved surface-similar objects. This pattern was also observed in studies with number line tasks [7], verb learning [40], spatial relations [41,42], and infant categorizations [43]. At the same time, there is evidence that lowering variability of objects can also dampen relational abstraction. For example, 18-month-old infants abstracted the grammar

Figure 1



The dependence of relational abstraction on object similarity in humans (left) and nonhumans (right) — a schematic representation.

rule aXb when training consisted of 24 variable X's, but not with 12 or fewer X's [44,45]. Taken together, these studies indicate that the capacity to see relational similarity varies with object variability as an inverted U. There appears to exist a level of variability optimal for children's relational abstraction, such that—relative to that optimum — more variability begets distraction while less variability obfuscates the relation (Figure 1).

This optimal point persists in adult relational reasoning, despite the shift in relative preference from object to relational similarity. A recent study found that adults were capable of abstracting rules (such as ABB) from two minutes' exposure to syllables (e.g. 'ga-la-la') or shapes (e.g. circle-triangle-triangle), but their abstraction deteriorated when object matches were present in the non-relational choices — for example in choosing between 'wo-**la**-wo' (new rule ABA and a partial object match 'la') and 'wo-fe-fe' (ABB, familiar rule) [46]. In another study [47], adults were slower to generalize relational patterns (horizontal and vertical) when the objects depicting those relations at training were swapped at test — for instance when objects used in horizontal training formed the vertical pattern at test. When the same objects depicted the same relations during training and test trials, participants were faster in noting the relational pattern.

Continuity despite differences

In sum, the following picture emerges: sensitivity to object similarity is both a prerequisite and a learning tool for being able to perceive a similarity of relations, and an initial sensitivity for object matches can be helpful in learning to see relations. This learning tool is available to humans and animals alike, but they do not use it in the same way: while human children show a strong initial preference for objects over relations, there is less evidence that nonhuman animals adopt that tactic. Indeed, the pattern of interaction between object and relational reasoning differs significantly across species. In nonhuman animals, current evidence suggests that object variability and relational focus enjoy a joint growth — greater object variability results in greater relational abstraction [35]. For humans, this relationship is more nuanced.

How do differences in the perception of object similarity affect species' relational reasoning? If a cognitive system does not start with a strong preference for object similarity — as is the case in baboons, chimpanzees, and bonobos — will it develop a compensating preference for relational similarity? Studies in nonhumans suggest an affirmative answer: from bees [48] to crows [25] to baboons [29], we have evidence that animals are capable of solving relational tasks. Yet humans are certainly the superior relational thinkers [2,4], despite an initial preference for objects over relations. Paradoxically, humans' early bias for object similarity may well be the key to their eventual relational prowess. Our superior relational attention is probably not the result of a discontinuous realignment; rather, it is likely a learned ability that builds on benefits accrued during an initial object-matching stage.

Conflict of interest statement

Nothing declared

Acknowledgements

This work is supported by Tsinghua University Initiative Scientific Research Program [grant number 20197010006]. I thank Bartlomiej Czech and Susan Carey for discussions on ideas put forward in this manuscript, and Yijin Fang for help in preparing this manuscript. I also thank Perimeter Institute for providing conducive environment for the writing of this manuscript.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- of special interest

1. Chi MTH, Feltovich PJ, Glaser R: **Categorization and representation of physics problems by experts and novices**. *Cogn Sci* 1981, **5**:121-152.

2. Gentner D: **Why we're so smart**. In *Language in Mind: Advances in the Study of Language and Thought*. Edited by Gentner D, Goldin-Meadow S. Cambridge, MA: MIT Press; 2003:195-235.

3. • Gentner D, Hoyos C: **Analogy and abstraction**. *Top Cogn Sci* 2017, **9**:672-693 http://dx.doi.org/10.1111/tops.12278

This paper explains how analogical reasoning — the ability to perceive relational similarity — gives rise to knowledge acquisition and abstraction.

4. Penn DC, Holyoak KJ, Povinelli DJ: **Darwin's mistake: explaining the discontinuity between human and nonhuman minds**. *Behav Brain Sci* 2008, **31**:109-130 http://dx.doi.org/10.1017/S0140525X08003543.

5. Christie S, Gentner D: **Relational similarity in identity relation: the role of language.** In In *Proceedings of the Second European Cognitive Science Conference.* Edited by Vosniadou S, Kayser D. *Proceedings of the Second European Cognitive Science Conference* 2007.

6. Christie S, Gao Y, & Ma Q: **Development of analogical**
• **reasoning: a novel perspectives from cross-cultural studies** *Child Dev Perspect* in press

A review of cross-cultural similarities and differences in humans' relational learning, including differences in relational versus object similarity reasoning between Western children (US, Australia, Europe) and East Asian (Chinese and Japanese) children. The review also analyzes the factors contributing to these differences.

7. Thompson CA, Opfer JE: **How 15 hundred is like 15 cherries: effect of progressive alignment on representational changes in numerical cognition**. *Child Dev* 2010, **81**:1768-1786 http://dx.doi.org/10.1111/j.1467-8624.2010.01509.x.

8. Childers JB, Parrish R, Olson CV, Burch C, Fung G, McIntyre KP: **Early verb learning: how do children learn how to compare events?** *J Cogn Dev* 2016, **17**:41-66 http://dx.doi.org/10.1080/15248372.2015.1042580.

9. Richland LE, Morrison RG, Holyoak KJ: **Children's development of analogical reasoning: insights from scene analogy problems**. *J Exp Child Psychol* 2006, **94**:249-273 http://dx.doi.org/10.1016/j.jecp.2006.02.002.

10. Yuan L, Uttal D, Gentner D: **Analogical processes in children's understanding of spatial representations**. *Dev Psychol* 2017, **53**:1098 http://dx.doi.org/10.1037/dev0000302.

11. Gentner D: **Structure-mapping: a theoretical framework for analogy**. *Cogn Sci* 1983, **7**:155-170 http://dx.doi.org/10.1016/S0364-0213(83)80009-3.

12. Gentner D, Markman AB: **Structure mapping in analogy and similarity**. *Am Psychol* 1997, **52**:45 http://dx.doi.org/10.1037/0003-066X.52.1.45.

13. Christie S, Gentner D: **Where hypotheses come from: learning new relations by structural alignment**. *J Cogn Dev* 2010, **11**:356-373 http://dx.doi.org/10.1080/15248371003700015.

14. Christie S: **Multiple exemplars of relations**. In *Learning Language and Concepts from Multiple Examples in Infancy and Childhood.* Edited by Childers J, Graham S, Namy L. Springer; 2020.

15. Anderson EM, Chang YJ, Hespos S, Gentner D: **Comparison**
• **within pairs promotes analogical abstraction in three-month-olds**. *Cognition* 2018, **176**:74-86 http://dx.doi.org/10.1016/j.cognition.2018.03.008

This study details the process of relational learning — that 3-month-old infants need multiple exemplars of object similarity in order to gain relational abstraction.

16. Gentner D, Namy LL: **Analogical processes in language learning**. *Curr Direct Psychol Sci* 2006, **15**:297-301.

17. Paik JH, Mix KS: **Preschoolers' use of surface similarity in object comparisons: taking context into account**. *J Exp Child Psychol* 2006, **95**:194-214 http://dx.doi.org/10.1016/j.jecp.2006.06.002.

18. Mix KS, Smith LB, Crespo S: **Leveraging relational learning**
• **mechanisms to improve place value instruction**. In *Constructing Number.* Edited by Norton A, Alibali MW. Cham: Springer; 2019:87-121 http://dx.doi.org/10.1007/978-3-030-00491-0_5

A review explaining how mathematics learning (with particular emphasis on place value concept) is a form of relational abstraction and that relational learning tools such as object similarity is useful in classroom settings.

19. Gervain J, Berent I, Werker JF: **Binding at birth: the newborn brain detects identity relations and sequential position in speech**. *J Cogn Neurosci* 2012, **24**:564-574 http://dx.doi.org/10.1162/jocn_a_00157.

20. Quinn PC: **The categorization of above and below spatial relations by young infants**. *Child Dev* 1994, **65**:58-69 http://dx.doi.org/10.1111/j.1467-8624.1994.tb00734.x.

21. Quinn PC, Cummins M, Kase J, Martin E, Weissman S: **Development of categorical representations for above and below spatial relations in 3-to 7-month-old infants**. *Dev Psychol* 1996, **32**:942.

22. Zentall TR, Edwards CA, Moore BS, Hogan DE: **Identity: the basis for both matching and oddity learning in pigeons**. *J Exp Psychol: Anim Behav Process* 1981, **7**:70.

23. D'Amato MR, Salmon DP: **Cognitive processes in cebus monkeys**. *Anim Cogn* 1984:149-168.

24. Thompson RKR, Oden DL: **Categorical perception and conceptual judgments by nonhuman primates: the paleological monkey and the analogical ape**. *Cogn Sci* 2000, **24**:363-396 http://dx.doi.org/10.1207/s15516709cog2403_2.

25. Smirnova A, Zorina Z, Obozova T, Wasserman E: **Crows spontaneously exhibit analogical reasoning**. *Curr Biol* 2015, **25**:256-260 http://dx.doi.org/10.1016/j.cub.2014.11.063.

26. Oden DL, Thompson RK, Premack D: **Spontaneous transfer of matching by infant chimpanzees (Pan troglodytes)**. *J Exp Psychol: Anim Behav Process* 1988, **14**:140.

27. Kuwabara M, Smith LB: **Cross-cultural differences in cognitive development: attention to relations and objects**. *J Exp Child Psychol* 2012, **113**:20-35 http://dx.doi.org/10.1016/j.jecp.2012.04.009.

28. Carstensen A, Zhang J, Heyman GD, Fu G, Lee K, Walker CM:
• **Context shapes early diversity in abstract thought**. *Proc Natl Acad Sci U S A* 2019, **116**:13891-13896 http://dx.doi.org/10.1073/pnas.1818365116

This study compared preschoolers from US and China on a version of Relational Match to Sample (RMTS) Task. In RMTS tasks without competing object matches, Chinese children matched relationally while US children performed at chance.

29. Fagot J, Thompson RKR: **Generalized relational matching by guinea baboons (Papio papio) in two-by-two-item analogy problems**. *Psychol Sci* 2011, **22**:1304-1309 http://dx.doi.org/10.1177/0956797611422916.

30. Christie S, Gentner D, Call J, Haun DBM: **Sensitivity to relational similarity and object similarity in apes and children**. *Curr Biol* 2016, **26**:531-535 http://dx.doi.org/10.1016/j.cub.2015.12.054.

31. Christie S, Gentner D: **Language helps children succeed on a classic analogy task**. *Cogn Sci* 2014, **38**:383-397 http://dx.doi.org/10.1111/cogs.12099.

32. Gentner D: **Language as cognitive tool kit: how language supports relational thought**. *Am Psychol* 2016, **71**:650 http://dx.doi.org/10.1037/amp0000082.

33. Thibaut JP, French RM: **Analogical reasoning, control and executive functions: a developmental investigation with eye-tracking**. *Cogn Dev* 2016, **38**:10-26 http://dx.doi.org/10.1016/j.cogdev.2015.12.002.

34. Wasserman E, Castro L, Fagot J: **Relational thinking in animals and humans: from percepts to concepts**. In *APA Handbooks in Psychology®. APA Handbook of Comparative Psychology: Perception, Learning, and Cognition.* Edited by Call J, Burghardt GM, Pepperberg IM, Snowdon CT, Zentall T. American Psychological Association; 2017:359-384 http://dx.doi.org/10.1037/0000012-017.

35. Castro L, Wasserman EA, Fagot J, Maugard A: **Object-specific and relational learning in pigeons**. *Anim Cogn* 2015, **18**:205-218 http://dx.doi.org/10.1007/s10071-014-0790-8.

36. Maugard A, Wasserman EA, Castro L, Fagot J: **Effects of training condition on the contribution of specific items to relational processing in baboons (Papio papio)**. *Anim Cogn* 2014, **17**:911-924 http://dx.doi.org/10.1007/s10071-013-0724-x.

37. Lazarowski L, Goodman A, Galizio M, Bruce K: **Effects of set size**
• **on identity and oddity abstract-concept learning in rats**. *Anim Cogn* 2019, **22**:733-742

This study shows effect size of training trials on rats' learning of MTS and RMTS tasks. The results are consistent with other animal studies: dissimilar objects results in better learning.

38. Daniel, Wright, Katz: *Abstract-concept Learning Of Difference In Pigeons* 2015, **vol 8**831-883 http://dx.doi.org/10.1007/s10071-015-0849-1.

39. Ferry AL, Hespos SJ, Gentner D: **Prelinguistic relational concepts: investigating analogical processing in infants**. *Child Dev* 2015, **86**:1386-1405 http://dx.doi.org/10.1111/cdev.12381.

40. Childers JB, Parrish R, Olson CV, Burch C, Fung G, McIntyre KP: **Early verb learning: how do children learn how to compare events?** *J Cogn Dev* 2015, **17**:41-66 http://dx.doi.org/10.1080/15248372.2015.1042580.

41. Casasola M: **When less is more: how infants learn to form an abstract categorical representation of support**. *Child Dev* 2005, **76**:279-290 http://dx.doi.org/10.1111/j.1467-8624.2005.00844.x.

42. Casasola M, Park Y: **Developmental changes in infant spatial categorization: when more is best and when less is enough**. *Child Dev* 2013, **84**:1004-1019 http://dx.doi.org/10.1111/cdev.12010.

43. Gerken LA, Quam C: **Infant learning is influenced by local spurious generalizations**. *Dev Sci* 2017, **20**:e12410 http://dx.doi.org/10.1111/desc.12410.

44. Gomez RL: **Variability and detection of invariant structure**. *Psychol Sci* 2002, **13**:431-436 http://dx.doi.org/10.1111/1467-9280.00476.

45. Sandoval M, Gomez RL: **The development of nonadjacent dependency learning in natural and artificial languages**. *Wiley Interdiscip Rev: Cogn Sci* 2013, **4**:511-522 http://dx.doi.org/10.1002/wcs.1244.

46. Orticio E & Christie S: **Object Bias Disrupts Rule-Based Generalization Across Domains.** In: Denison S, Mack M, Xu Y, & Armstrong B. (eds.). *Proceedings of the 42nd Annual Meeting of the Cognitive Science Society* (in press)

47. Rein JR, Markman AB: **Assessing the concreteness of relational representation**. *J Exp Psychol: Learn Mem Cogn* 2010, **36**:1452 http://dx.doi.org/10.1037/a0021040.

48. Giurfa M, Zhang S, Jenett A, Srinivasan MV: **The concepts of 'sameness' and 'difference'in an insect**. *Nature* 2001, **410**:930-933 http://dx.doi.org/10.1038/35073582.