Symmetry: Low-level visual feature or abstract relation?

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Abstract

We traced the development of sensitivity to symmetric relational patterns by creating a symmetry match-to-sample task. Children saw a symmetric standard made up of two shapes and choose between two novel alternatives: a symmetric pair and an asymmetric pair. We found that young children chose randomly between the two alternatives. Children were not reliably above chance until 8-to 9 years of age. In a second study, we found that young children could succeed in making symmetric relational matches if the triads were designed to invite informative comparisons. These findings show that relational insight of symmetry develops relatively late. However, as with other relations, comparison processes can promote sensitivity to the symmetry relation.

Keywords: symmetry; relational processing; comparison and contrast

Introduction

The acquisition and use of relational concepts are critical to higher-order cognition, and to learning in complex domains. Symmetry is arguably one of the most basic and ubiquitous relations in nature, evident in structures as small as molecules and as large as blue whales. Non-human animals are thought to show a preference for symmetrical over asymmetrical bodily features when choosing a mate, and there is evidence that humans rate symmetrical faces as more attractive than non-symmetrical ones (e.g., Grammer & Thornhill, 1994; Møller, & Thornhill, 1998). Based on these patterns, some researchers have suggested that sensitivity to symmetry may be biologically endowed (e.g. Grammer & Thornhill, 1994).

Evidence in favor of this claim comes from three lines of research. First, symmetry is easily processed by the human visual system (e.g., Wagemans, 1997). Researchers have suggested that symmetry detection is an automatic process that is rapid and robust to noise (Carmody, Nodine, & Locher, 1977; Royer, 1981). Symmetry processing is also thought to be a fundamental component of perceptual organization, playing a crucial role in object representation (e.g., Driver, Baylis, & Rafal, 1992; Marshall & Halligan, 1994).

Second, symmetry processing is widespread across species. Dolphins, pigeons, bamboo sharks, and bees are all capable of learning to discriminate between symmetric and asymmetric objects (Delius & Nowak, 1982, Giurfa, Eichmann, & Menzel, 1996, Schluessel et al., 2014, von Fersen et al., 1992).

A third point is that sensitivity to symmetry is early to emerge in human infants. Human children are sensitive to symmetry from infancy, although vertical symmetry is typically more readily perceived than horizontal symmetry. For example, using a habituation-dishabituation paradigm, Fisher, Ferdinandsen, and Bornstein (1981) found that 4-month-olds discriminated vertically symmetric single objects from those that were horizontally symmetric or asymmetric, but did not discriminate between horizontally symmetric and asymmetric objects. Other researchers have found converging results with older children (Bornstein and Stiles-Davis, 1984; Chipman & Mendelson, 1979).

The findings reported above have all focused on within-object symmetry. Taken together, they suggest that within-object symmetry may be a low-level visual feature that is universally detected. However, symmetry is not confined to single objects—many scientific discoveries emerge from detecting symmetrical patterns between objects or events (e.g., Gross, 1996). We want to raise the possibility that discriminating within-object symmetry is quite different from detecting symmetry between two or more distinct objects; the latter requires symmetry to be construed as a relation while the former does not. Although previous research on symmetry processing has revealed much on how humans and non-human animals perceive symmetry within a single object (see Cattaneo, 2017; Giannouli, 2013; Treder, 2010; Wagemans, 1997 for reviews), comparatively little is known about the development of the ability to recognize and match symmetry between objects. This paper aims to shed light on the development of children's insight of the between-object symmetry relation.

Is Symmetry the Basis for *Same/Different* Detection?

A secondary motivation for examining children's ability to detect and match symmetry relations is to explore how symmetry pertains to other fundamental relational concepts, such as *same* and *different*.

If between-object symmetry is fluently processed, as a low-level visual feature, even by very young children, it is possible that symmetry detection may inflate children's performance on *same/different* relational tasks. In an insightful analysis, Hochmann and colleagues (2017) discussed this possibility. They pointed out that in many *same/different* relational tasks, *same* pairs are also symmetrical (e.g., [O,O]), whereas *different* pairs are asymmetrical (e.g., [O,X]). Thus, participants could potentially pass such tasks by responding to symmetry.

Walker and Gopnik (2017) reported evidence that runs against this contention. Using a relational causal paradigm (the "Blicket Detector"), they found that 18-to 30-month-olds could learn to discriminate between *different* pairs (e.g., [A, B]) and *same* pairs (e.g., [Ɔ, C]). Note that, as discussed above, the *different* pair is asymmetrical and the *same* pair is symmetrical, leaving open the question of whether the children were relying on symmetry rather than sameness. However, when the objects were fused together to form either a single symmetrical object (made from two identical objects) or a single asymmetrical object (made from two different objects), the toddlers failed to learn the discrimination. These findings suggest that within-object symmetry is not the basis for the children's performance on this *same/different* relational task. However, it does not address whether between-object symmetry detection influences *same/different* detection.

Can Children Detect Symmetry Between Objects?

One study that explicitly examined whether children can detect symmetry between objects was done by Kotovsky and Gentner (1996). They presented 4-, 6-, and 8-year-olds with a relational matching task in which children were given a standard composed of three figures and had to choose which of two alternatives was more like the standard. One of the alternatives matched the standard's relation and the other had the same objects in a nonmatching configuration (see Figure 1). Within each trial, the two alternatives included the same objects. Children were given a random mixture of four trial types that differed across dimension and polarity.

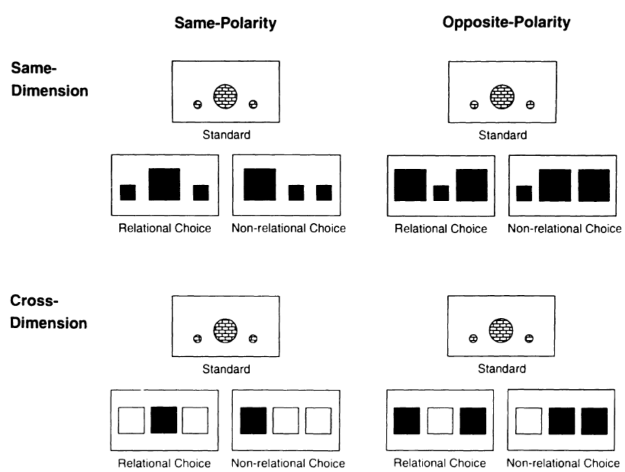

Figure 1: Schematics of stimuli used in Kotovsky and Gentner (1996).

The 6-and 8-year-olds performed well on this task. In contrast, 4-year-olds performed above chance only on trials where the correct alternative and the standard shared a concrete relation—same dimension and same polarity (Figure 1 top left panel). In these trials, the standard and the correct relational alternative share an overall shape (a low-high-low or an inverted V pattern), so it is not clear whether the 4-year-olds were attending to the relational pattern that defines symmetry or were instead simply responding to the common low-high-low shape.

The Kotovsky and Gentner (1996) study provides evidence that, at least by 6 years of age, children can perceive symmetry as a relation between objects, as well as make relational matches based on symmetry. Previous research has shown that children can make abstract *same/different* relational matches by 4 years of age without practice (e.g. Christie & Gentner, 2014), whereas the 4-year-olds in Kotovsky and Gentner's study were only able to make concrete symmetry matches. Further, we cannot confidently extrapolate from Kotovsky and Gentner's findings with 6- and 8-year-olds to the case of symmetric pairs like [Ɔ, C], because the figures in Kotovsky and Gentner's study (1996) all involved three objects. Although these are more complex than two-object figures, it could be that the larger patterns are easier to perceive.

In the current work, we trace the trajectory of children's ability to perceive and match symmetry in a task analogous to a classic *same/different* relational matching task in order to facilitate comparison of the developmental trajectories of these two relations. If we find that between-object symmetry matching is mastered earlier than same-different matching, this will leave open the possibility that same-different judgments could be drawing on symmetry perception.

Current Studies

The current work aims to (1) trace the development of human children's ability to detect and use the symmetry relation; and (2) investigate the learning processes by which children gain insight into the symmetry relation.

To do so, we created a Symmetry-Match-to-Sample task (SMTS) by analogy with the Relational-Match-to-Sample (RMTS) task (Christie & Gentner, 2014; Hochmann et al., 2017; Premack, 1983, Thompson, Oden, & Boysen, 1997). The RMTS task assesses understanding of *same* and *different* relations. For example, to assess the ability to match the *same* relation, the RMTS triad is AA (standard), BB & CD (alternatives). It is designed so that there is only one viable similarity match—the relational match based on the *same* relation. Analogously, in the SMTS task, children are shown a symmetric standard and asked to choose which is more similar: another symmetric pair, or an asymmetric pair. The standard and alternatives did not share any common objects, so there was only one viable choice (See Figure 2a).

Experiment 1

Methods

Participants One hundred 3-to 9-year-olds participated in this study: 19 3-year-olds (*M* = 42.8 months, *SD* = 2.3 months, 11 females), 21 4-year-olds (*M* = 53.6 months, *SD* = 3.4 months, 11 females), 20 5-year-olds (*M* = 68.4 months, *SD* = 1.6 months, 10 females), 20 6-year-olds (*M* = 80.4 months, *SD* = 1.8 months, 11 females), and 20 8- to 9-year-olds (*M* = 105.8 months, *SD* = 7.5 months, 9 females). An additional 11 children were tested but excluded from the final analysis, one child due to experimental error and ten children due to failing to pass the catch trials described below (one 4-year-old and nine 3-year-olds). The racial and economic composition of the sample reflected those of the local population (majority European-American, middle- and upper-middle-class). All children were recruited from the greater Chicago area and received a small gift for their participation.

Materials and Procedure Children completed a Symmetry-Match-to-Sample (SMTS) task. The SMTS included eight test trials and three catch trials. Each trial was composed of a standard card and two alternative match cards (see Figure 2). The child was asked to choose the alternative that was most like the standard. In all test trials, the standard and correct match both depicted two identical shapes that were symmetric around the vertical axis; the incorrect match card showed two shapes that were in an asymmetric configuration (Figure 2a). Within a triad, each card was made up of unique shapes and colors.

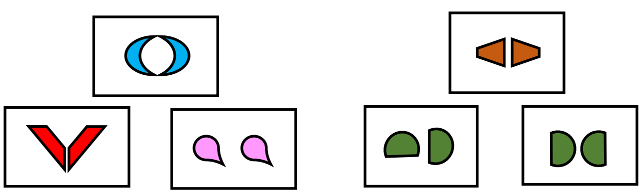

Figure 2: a. Sample test trial from Exp. 1: SMTS; b. Sample test trial from Exp. 2: SMTS with Comparable Alternatives.

After the test trials, there were three catch trials to determine whether the participants understood the task. These catch trials were literal similarity matches that did not require the child to judge relational similarity. For example, on one of the catch trials, children saw a red fish as the standard and had to choose between a blue fish (correct match) and a yellow cup. Children who failed any of the catch trials were not included in the analysis ($n = 10$).

Children were tested individually by an experimenter in a quiet room in the child's school or in a research laboratory. On each trial, the experimenter first presented the standard card and asked, "Do you see this one?" Then she placed the two alternative cards below the standard (as in Figure 1) and asked "Do you see these two? Which one of these two is more like this one?" Left/right placement of the alternatives was counterbalanced and no more than two subsequent trials had the correct match on the same side. Children were not given corrective feedback; only general encouragement (e.g., "You were so fast!", "Alright!") was provided.

Results

We measured the mean proportion of relational matches participants made in the eight test trials of the SMTS task. A one-way ANOVA revealed no difference in performance across the age groups, $F(4,95) = 1.16$, $p = .33$, $\eta 2 = 0.05$. When we compared the means of each age group to chance (50%), we found that only the 8- to 9-year-olds ($M = 0.69$, $SD = 0.27$) selected relational matches significantly more than chance, $t(19) = 3.17$, $p = .005$. The younger groups scored at chance (6-year-olds [$M = 0.57$, $SD = 0.29$]; 5-year-olds [$M = 0.59$, $SD = 0.28$]; 4-year-olds [$M = 0.61$, $SD = 0.26$]; 3-year- olds [$M = 0.53$, $SD = 0.15$]; all *p*s > .05]. Figure 3 shows the mean percentage of correct responses in each age group.

To assess whether learning occurred across trials despite the absence of feedback, we compared the proportion of correct matches that children made in the first three trials with that of the last three. There were no differences between the

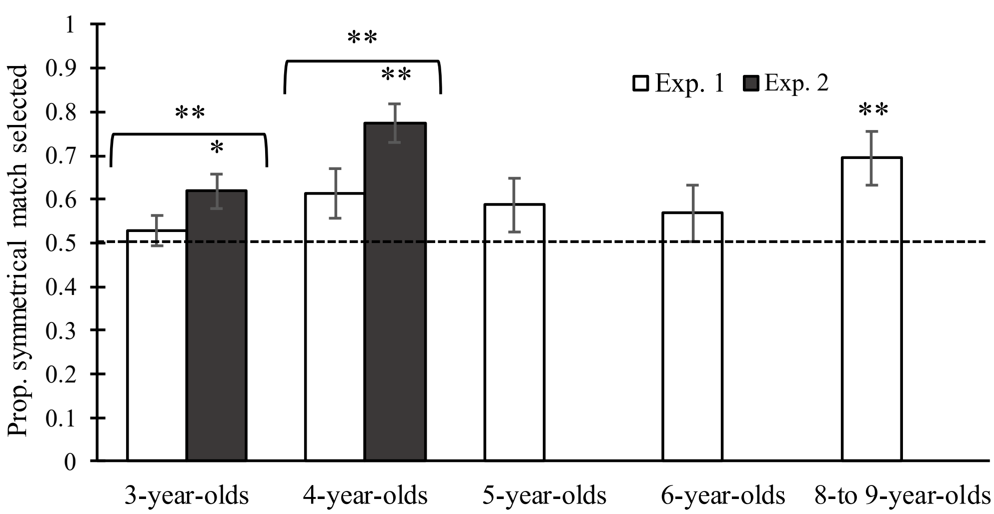

Figure 3: Mean proportion of symmetrical matches selected by children in Experiment 1: SMTS and Experiment 2: SMTS with Comparable Alternatives. Error bars depict standard error. * p < .05; ** p < .01

two in any age group, all *p*s > .13. Thus, performance did not improve across the eight test trials.

Discussion

The SMTS task was surprisingly challenging for children. Children who were six years of age or younger performed at chance rates. Even the 8- to 9-year-olds, who chose the relational match at significantly above chance rates, were only correct 69% of the time. It is unlikely that the younger age groups' poor performance was due to a failure to understand the task, since all participants were correct on the catch trials.

Why did children perform so poorly on the SMTS task compared to the findings in Kotovsky and Gentner? Kotovsky and Gentner (1996) found that 6-and 8-year-olds, and even 4-year-olds to a lesser extent, were able to make relational matches based on between-object symmetry. We propose that a crucial difference between our Experiment 1 and the Kotovsky and Gentner study was how much the experimental design scaffolded children's detection of the target relation.

Research has shown that an effective way to promote relational reasoning is by decreasing the salience of individual objects (Gentner & Rattermann, 1991; Goldstone & Son, 2005; Kaminski, Sloutsky, & Heckler, 2008). In similarity tasks, young children and novices tend to focus on objects rather than relations, and this can impede their relational processing (Gentner, 1988; Gentner & Toupin, 1986; Richland, Morrison, & Holyoak, 2006). In many studies, object salience has been reduced by using simple and uniform objects (Gentner & Rattermann, 1981; Mix, 2008). Kotovsky and Gentner (1996) further reduced object salience by presenting children with triads in which the two alternatives shared the same objects and differed only in the relation between the objects.

We hypothesize that using comparable alternatives promoted children's symmetry matching for two reasons: (1) using the same objects in both alternatives invites spontaneous comparison between them, and this may call attention to the key relational difference—that one is symmetric and the other is not; and (2) using the same objects in the two alternative pairs allows the child to discount object matches in making their choice and focus instead on any relations they may have perceived. In Experiment 2, we test this hypothesis by presenting children with a version of the SMTS that utilized comparable alternatives. We focused on the two younger age groups—the 3-and 4-year-olds.

Experiment 2: Comparable Alternatives

Methods

Participants Twenty 3-year-olds ($M = 44.7$ months, $SD = 1.8$ months, 9 females) and twenty 4-year-olds ($M = 53.1$ months, $SD = 3.2$ months, 11 females) were recruited for this experiment using the same methods as Experiment 1. Six additional children (four 3-year-olds) participated in the study but were excluded from analysis due to failing at least one of the catch trials.

Materials and Procedure As in Experiment 1, we created a relational matching task based on the symmetry relation. However, we modified the alternatives so that the two alternatives in a given trial consisted of the same objects, one in a symmetric configuration and the other in a non-symmetric configuration (see Figure 2b). The catch trials and procedure were as in Experiment 1.

Results

The mean proportions of relational matches are shown in Figure 3. Two-tailed one sample t-tests revealed that both 3-year-olds ($M = 0.62$, $SD = 0.18$) and 4-year-olds ($M = 0.78$, $SD = 0.20$) performed significantly better than chance, $t(19) = 2.97$, $p = .008$, and $t(19) = 6.24$, $p < .001$, respectively. However, the 4-year-olds made a significantly higher proportion of relational matches than the 3-year-olds, $t(38) = 2.63$, $p = .01$. Children in both age groups performed equally well on the first three and last three trials (all *p*s > .05).

We next compared the performances of the 3-and 4-year-olds in the current experiment (Comparable Alternatives condition) and those in Experiment 1. A two-way ANOVA revealed a significant main effect of age (3-year-olds vs. 4-year-olds, $F(1,76) = 7.19$, $p = .009$) and a significant main effect of condition (Experiment 1 vs. Experiment 2, $F(1,76) = 7.88$, $p = .006$). The interaction between age and condition was not significant. In both experiments, 4-year-olds performed better than 3-year-olds. Both age groups performed better in Experiment 2 than Experiment 1.

Discussion

Consistent with our hypothesis, 3-and 4-year-olds performed well on the SMTS when presented with alternatives that were composed of the same objects, but in different relational configurations. Both age groups performed significantly better in Experiment 2 than in Experiment 1. In addition, both 3-and 4-year-olds chose the symmetric match at above chance rates, whereas only the 8-and 9-year-olds in Experiment 1 were able to do so.

The two alternatives in Experiment 2 were extremely similar— the same object was used to form the object pairs on both alternative cards, with the only difference being the symmetric or asymmetric configuration between the objects. As noted above, we hypothesized that this would have two advantages: first, common objects can invite comparison between the alternatives, and this may lead to noticing that the relational patterns differ; and, second, when the same objects are used in both alternatives, children should be less likely to rely on object matches to discriminate between them, thus inviting attention to the previously less salient relational information (e.g., Mix 2008).

Consistent with this prediction, children performed markedly better in Experiment 2 than in Experiment 1. When the relation depicted by each alternative card was more salient, the process of detecting and matching these relations (comparison and contrast) seemed to be more fluent. Thus, 3- and 4-year-olds who previously were not able to pass the SMTS were able to do so when presented with comparable alternatives.

General Discussion

Across two experiments, we explored children's ability to perceive and match symmetry between two objects using a Symmetry-Match-to-Sample (SMTS) task. In Experiment 1, we found a long developmental course for between-object symmetry matching: children did not pass the task until after 6 years of age.

In Experiment 2, we explored the method of Comparable Alternatives in facilitating children's relational insight. We presented children with a matching task in which the two alternatives were composed of the same objects. With Comparable Alternatives, even 3-and 4-year-olds chose the symmetric match at significantly above chance rates. We propose that there were two reasons for this improvement. First, the common objects promoted online comparison between the two alternatives, setting the stage for children to discover the crucial difference between them—whether or not the two objects in each alternative were symmetrical to each other. Second, using common objects in the two alternatives signaled to the children that object similarity could not be the basis for matching, thus allowing them to shift their attention to relations.

Symmetry does not inform *Same/Different* Detection

The present findings provide evidence against the claim that symmetry detection informs *same/different* detection. Researchers have consistently found that 4-and 5-year-olds can pass the standard Relational-Match-to-Sample (RMTS; with unique objects) task without any prior training, corrective feedback, or linguistic assistance (Christie & Gentner, 2014; Hochmann et al., 2017, Hoyos, Shao, & Gentner, 2016). However, children do not pass a similar Symmetry-Match-to-Sample (SMTS) task (Experiment 1) until after 6 years of age. Taken together, these findings suggest that children are not passing the RMTS by responding to symmetry. In fact, between-object symmetry matching appears to emerge later than *same/different* matching.

Bootstrapping relational insight

Because of the importance of comparison in acquiring relational insight, a number of techniques have been explored for promoting relational comparison. One such technique is Progressive Alignment—the phenomenon whereby carrying out relatively concrete and easy-to-align matches promotes subsequent ability to match less surface-similar, more challenging pairs that instantiate the same relation (e.g., Gentner, Loewenstein, & Hung, 2007; Haryu, Imai & Okada, Kotovsky & Gentner, 1996; Loewenstein & Gentner, 2001).

In Kotovsky and Gentner's (1996) initial study, 4-year-olds only succeeded on trials that involved concrete matches, suggesting that they did not have an abstract representation of the symmetry relation. In a follow-up study, Kotovsky and Gentner (1996) presented a new group of 4-year-olds with the same trials as before, but in an order designed to promote progressive alignment. Children were first shown a block of concrete (within-dimension) trials and then progressed on to more abstract (across-dimension) trials. The 4-year-olds showed a gain in performance on the abstract trials.

The technique used in Experiment 2—Comparable Alternatives—is another way to scaffold children's relational insight. Here, the two alternatives share the same objects but instantiate different relations, only one of which matches the standard. This design not only promotes comparison between the two alternatives, potentially highlighting the relational difference, but also de-emphasizes the role of objects, signaling that objects are not the basis for matching.

To our knowledge, the current study is the first to explicitly investigate whether the use of comparable alternatives is a way to promote relational insight. Prior studies have used alternatives that share common objects in relational matching tasks, but have not investigated whether this procedure promotes relational insight than using standard dissimilar alternatives (e.g., Kotovsky & Gentner, 1996; Mix, 2008). We are currently investigating whether presenting children with relatively easy comparable alternatives trials could serve to bootstrap later performance on the more abstract SMTS—analogous to progressive alignment.

Within-Object Versus Between-Object Symmetry

In this paper, we focused on a relatively overlooked aspect of children's symmetry development—the ability to detect and match between-object symmetry. Our findings contrast with a large body of research on within-object symmetry detection that has viewed symmetry as a low-level visual feature. We found evidence suggesting that between-object symmetry—at least for 3- and 4-year-olds—can be perceived and processed as a relation. As with other relations, children's initial relational representations may be quite concrete (Gentner, 2010); but further experience—notably experience in comparing examples (and nonexamples) of the relation—can lead to more abstract, portable representations.

This leads to the question of whether the representations and mechanisms that support processing within-object symmetry are the same as those that support processing between-object symmetry. For example as noted above, there is evidence that many animals can detect within-object symmetry. Can the same species detect between-object symmetry, and can they construe symmetry as an abstract relation?

Although we do not have the answers to these questions, we propose that researchers may take inspiration from the existing rich literature on *same/different* processing. Premack (1983), among others, has proposed species graded differences in relational reasoning ability (see also Gentner, 2003; 2010; and Penn, Povinelli & Holyoak, 2008). A substantial body of empirical findings supports this proposal. For example, there are more species that can learn to discriminate between *same* and *different* pairs (e.g., rhesus macaques [Katz, Wright, & Bachevalier, 1984] than species that can learn to make relational matches based on *same*/*different* pairs, hence passing the Relational-Match-to-Sample task (e.g., chimpanzees [Premack, 1983; Thompson, Oden, & Boysen, 1997]; and hooded crows [Smirnova, Zorina, Obozova, & Wasserman, 2015]). Does a similar distinction hold for symmetry? If so, we would expect to see a gradient between species that can detect symmetry and those that can pass a Symmetry-Match-to-Sample task, as investigated here.

Conclusions

The present work provides an initial exploration of the development of insight into the symmetry relation. Using a Symmetry-Match-to Sample task, we found that the ability to process relational matches based on symmetry emerges relatively late in development. However, as with other relations, insight into the symmetry relation can be scaffolded through comparison processes. The present work also explores a novel way of promoting relational insight—using comparable alternatives that share objects but not relations. These findings underline the importance of comparison in supporting children's understanding of symmetry and other relations.

Acknowledgements

This work was supported by the Office of Naval Research, ONR grant N00014-16-1-2613 to Dedre Gentner. We thank the children and families who participated in this research, members of the Cognition and Language Lab for help with data collection, and Christian Hoyos for his insightful comments.

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