The paradox of relational development is not universal: Abstract reasoning develops differently across cultures

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Abstract

Recent studies demonstrate a puzzling decline in relational reasoning during development. Specifically, 3-year-olds fail in a relational match-to-sample (RMTS) task, while younger children (18-30 months) succeed (Walker, Bridgers, & Gopnik, 2016). Hoyos, Shao, and Gentner (2016) propose that older children fail because of a bias toward individual object properties induced by "avid noun learning." If this is the case, children learning a language with a stronger emphasis on verbs, like Mandarin Chinese, may show an attenuated decline in relational reasoning. We first test this possibility by reproducing the causal RMTS task in China, and find that Mandarin-speaking 3-year-olds outperform their English-speaking peers in the U.S. In a second experiment, we show that Mandarin speakers exhibit a corresponding bias toward relational solutions while English speakers prefer object-based solutions in an ambiguous context. We discuss possible mechanisms through which language and culture may promote (or hinder) the early development of relational reasoning.

Keywords: cognitive development, causal learning, relational reasoning, overhypotheses, language, culture.

The puzzling decline of relational reasoning

Relational reasoning is often cited as a defining feature of human cognition (e.g., Gentner, 2003), and a source of the differences between the abilities of humans and other primates (Penn, Holyoak, & Povinelli, 2008). The ability to recognize relational similarities appears surprisingly early in human development: 7- and 9-month-old infants distinguish the abstract relations "same" and "different," looking longer at novel pairs of objects that differ from a habituated relation (Ferry, Hespos, & Gentner, 2015; Tyrrell, Stauffer, & Snowman, 1991).

Toddlers (18-30 months) can also employ these concepts to infer abstract causal properties in a relational match-to-sample task (Walker & Gopnik, 2014). In this task, children observe as four pairs of blocks are placed on a toy that plays music when "activated." Two of the pairs contain identical blocks ("same") and the other two pairs contain mismatched blocks ("different"). For toddlers in the *same* condition, the toy activates and plays music only when the "same" pairs are placed on top, while those in the *different* condition observe the opposite pattern. When shown novel pairs of "same" or "different" blocks and asked to choose which pair would activate the toy, toddlers succeed in picking the pair that is relationally consistent with their training.

However, this early success in relational reasoning is quickly followed by a puzzling decline: 3-year-olds (36-48 months) fail to select the relational solution in precisely the same task (Walker, Bridgers, & Gopnik, 2016). Similar difficulties have also been observed in a variety of relational reasoning tasks (e.g., Christie & Gentner, 2007; 2010; 2014; Gentner, 1988; 2010; Hoyos, Shao, & Gentner, 2016). By 4 years of age (52-60 months), children once again succeed in a standard RMTS task (Christie & Gentner, 2014), but continue to neglect relational similarities in other contexts even at 5-6 years of age (e.g., Gentner, 1988). This pattern of early success, decline, and reemergence suggests that the development of relational reasoning may follow a U-shaped trajectory, rather than a continuous process of gradual improvement, as previously suggested (e.g., Gentner & Medina, 1998). What causes this curious dip in children's relational reasoning?

One possibility is that preschoolers retain an early competence to reason about relations, but that this competence is overshadowed by a failure to attend to relational structure. In particular, Walker et al. (2016) suggest that 3-year-olds neglect relational information as a result of a *learned* bias to attend to individual object kinds and their properties. This claim is consistent with a large literature demonstrating that preschool-aged children attend to objects and attributes, and proposals that children must overcome an "entity-based view" in order to effectively process relations (Christie & Gentner, 2010; also, e.g., Christie & Gentner, 2007; 2014; Gentner, 1988; Gentner & Rattermann, 1991; Hall & Waxman, 1993).

Several proposals link this well-documented object bias to language development, which has been shown to both foster and impair relational reasoning (e.g., Christie & Gentner, 2014; Hoyos, Shao, & Gentner, 2016). These seemingly incongruous findings have led some to regard the contradictory effects of language on relational thinking as a developmental paradox (Hoyos, Shao, & Gentner, 2016).

Noun learning and relational development

In a recent paper, Hoyos, Shao, and Gentner (2016) suggest that the decline of relational reasoning may stem from an object bias induced by language learning. They reason that

"avid noun-learning" in early childhood likely leads to a "captivation with objects," which in turn helps children to learn additional nouns. In support of this view, they provide evidence that an experimentally induced noun bias interferes with relational reasoning. In this experiment, they replicate a previously published finding (Christie & Gentner, 2014) that 4-year-olds succeed on a standard RMTS task in a baseline condition, but show that priming nouns in a picture-labeling activity significantly reduces subsequent RMTS performance. On its own, this outcome suggests that language learning—and an emphasis on nouns in particular—may negatively impact relational reasoning in toddlers.

However, earlier work by Christie and Gentner (2014) leads to the opposite conclusion, that linguistic concepts—and nouns in particular—*facilitate* relational reasoning in the standard RMTS task. They find that providing children with a novel noun ("truffet") for pairs of objects improves toddlers' subsequent RMTS performance. Here, and elsewhere, the authors argue that young children do not initially have access to a hypothesis space that is "sufficient to allow for the range of possible semantic categories" but instead form hypotheses about relational meanings by comparing co-labeled items to identify common structure (Christie & Gentner, 2010).

Taken together, this account and the conflicting findings create an apparent paradox, in which a linguistic emphasis on nouns orients young learners *away* from relations, but language simultaneously provides the necessary scaffolding for relational learning by highlighting relational structure. In this way, language learning appears to solve the very problem it creates. Accordingly, this account implies that language learning may be interpreted as a double-edged sword, drawing attention to objects at the expense of relations, but in doing so, ultimately helping children to construct novel relational categories.

Language as a driver of children's hypotheses

The current research further explores the hypothesis that language learning influences the types of concepts and categories that young children entertain. Under the paradox account presented above, language learning helps children develop new relational categories to further populate their hypothesis space. An alternative possibility is that children have access to both relational and object-based hypotheses throughout development, but that the probabilities assigned to each type of hypothesis change as a result of prior knowledge and past experience, including language learning. This account draws on probabilistic models of cognitive development in which children are seen as Bayesian learners (e.g., Gopnik & Wellman, 2012), who weight the *likelihood* of a given hypothesis (the probability of the data given the hypothesis) by its *prior* probability (the general probability of the hypothesis, before any data are observed). Consequently, if a hypothesis has high prior probability, it will require stronger data to overturn it. This reasoning may also be applied to entire categories of hypotheses in the form of an overhypothesis, a general principle by which the learner assigns higher prior probability to particular types of hypotheses (Kemp, Perfors, & Tenenbaum, 2007). From this perspective, the "noun explosion" in early language learning could motivate an object bias—and temporary dip in relational reasoning—in the form of an overhypothesis that privileges object-based hypotheses over relational ones (for a discussion of language-induced overhypotheses and their relevance beyond language, see Colunga & Smith, 2005). By this account, language acts as one of many possible influences that affect a learner's hypothesis space, not by providing for new hypotheses (as the paradox view suggests), but by adjusting children's existing prior expectations.

Despite this distinction, both of these accounts leave room for an important role of language in driving children's relational reasoning, and both predict that a noun focus in word learning would (at least initially) bias children toward object properties and away from relations.

Previous demonstrations (e.g., Christie & Gentner, 2010; Hoyos, Shao, & Gentner, 2016) have tested this hypothesis indirectly, showing that immediate exposure to nouns modulates success on RMTS tasks, presumably by directing the learner's attention toward or away from relational information. However, these findings (which may reflect simple priming effects) do not necessarily demonstrate a relationship between noun focus in word *learning* and RMTS performance, as the experimental groups all involve English speakers, without any systematic between-group differences in degree of noun focus.

Conveniently, not all word learning follows the same trajectory. In particular, the "noun explosion" that has been documented in English-language learners is not universal across languages. In Korean, for instance, there is evidence for a comparable "verb spurt" (Choi & Gopnik, 1995). Similarly, several studies have found that children learning Mandarin Chinese produce more verbs than nouns in their spontaneous speech (both types and tokens), in contrast with English speakers of the same age, who produce a greater proportion of nouns than verbs (Tardif, 1996; Tardif, Shatz, & Naigles, 1997).

If an emphasis on noun learning (relative to other parts of speech) indeed drives the dip in relational reasoning by fostering an object bias, then children learning a more verb-centric language should show an attenuated or reversed bias. While nouns may direct focus to object properties by relying on these in picking out meanings, verbs often signal relational meanings across multiple entities, and might serve to redirect attention accordingly.

The difference in noun focus between English and Mandarin Chinese therefore presents two natural conditions in word learning, which we exploit as a test of the proposal that properties emphasized in word learning induce a bias in reasoning more generally.

Experiment 1: Causal relational reasoning in Mandarin-speaking children

To test for a relationship between noun focus in word learning and relational reasoning, we first reproduced Walker et al.'s (2016) causal RMTS task (see Figure 1) with Mandarin-speaking children (36-48 months) in China.

Methods

Participants. A total of 64 Mandarin-speaking 36-48-month-olds (M = 42.1 months; 28 female) took part in Experiment 1. This sample size was chosen based on previously published studies using the same paradigm. Participants were pseudo-randomly assigned to either the *same* or *different* condition. Five additional participants were excluded due to experimenter error or failure to complete the study. All participants were native speakers of Mandarin Chinese, and were recruited and tested at preschools in China.

Materials and procedure. The materials and procedure replicated those used in Experiment 1 of Walker et al. (2016), with the exception that instructions were given in Mandarin Chinese. The original English instructions (described here in English) were independently translated and backtranslated to ensure accuracy.

Children were tested individually, seated at a table across from the experimenter. The causal RMTS task began after a brief warmup to familiarize the child with the experimenter. During the task, the experimenter placed matching and mismatched pairs of painted wooden blocks on top of a box which appeared to play music in response to certain blocks. In reality, the experimenter activated a wireless doorbell inside the box by surreptitiously pushing a button.

The experimenter began by placing an opaque cardboard box on the table, saying "This is my toy! Sometimes it plays music when I put blocks on top and other times it does not. Should we try some and see how it works?" The experimenter then produced two blocks, said "Let's try!" and put both blocks on top of the toy simultaneously. The toy played music and the experimenter said "Music! My toy played music!" The experimenter picked up the blocks and set them back on the toy, which again played music, saying "Music! These ones made my toy play music!" She then repeated this procedure with a new pair of blocks in the opposite relation. The new pair did not make the toy play music, and the experimenter responded to the first try with "No music! Do you hear anything? I don't hear anything," and after the second try, said "No music. These ones did not make my toy play music." This pattern was repeated with two additional pairs of blocks. The experimenter always began with a causal pair (identical blocks in the *same* condition and blocks of differing colors and shapes in the *different* condition), and alternated inert, causal, inert, using novel blocks in each new pair, and randomizing the specific blocks between participants.

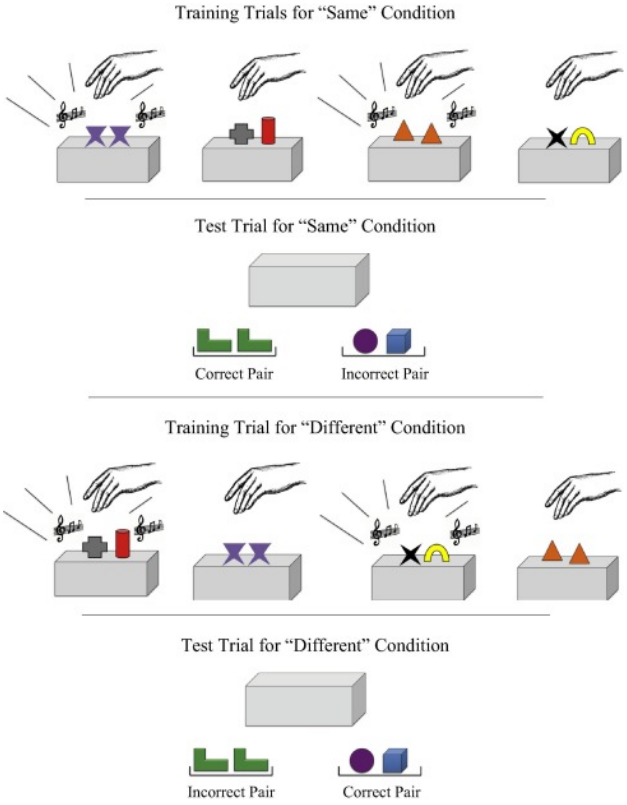

Figure 1: Schematic illustration of training and test trials in Experiment 1. Reprinted from Walker et al. (2016).

After the four training trials, the experimenter said "Now that you've seen how my toy works, I need your help finding the things that will make it play music. I have two choices for you." The experimenter presented the child with two new pairs made of novel blocks, one "same" pair and one "different." Each pair was supported by a tray, which the experimenter held up as she said "I have these…and I have these. Only one of these trays has things that will make my toy play music. Can you point to the tray that has the things that will make it play?" They trays were placed on either side of the toy, just out of reach of the child, with the side of the correct pair and order of presentation counterbalanced between participants. The experimenter recorded the child's first point or reach, and scored the answer as correct if the child chose the test pair (same or different) that corresponded to her training.

Results and discussion

Mandarin-speaking preschoolers selected the test pair that was consistent with their training in both same (69%; one-tailed binomial p = .025) and different (72%; one-tailed binomial p = .010) conditions (see Figure 2).[1]

[1] One-tailed binomial tests reflect the directional nature of our hypothesis, but the outcome is comparable with two-tailed tests (same: p = .052; different: p = .020).

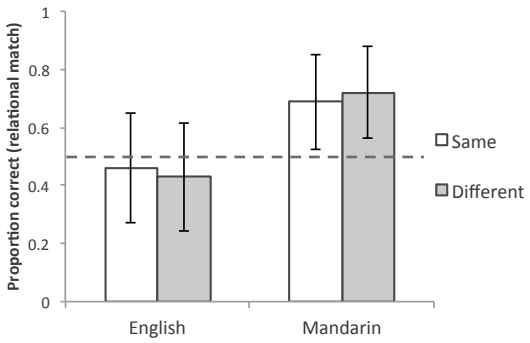

Figure 2: Proportion of correct relational matches selected by English- and Mandarin-speaking toddlers. English speaker data is reproduced from Experiment 1 of Walker et al. (2016). Error bars indicate 95% confidence intervals.

As predicted, Mandarin-speaking preschoolers succeed in the RMTS task at an age at which their English-speaking counterparts fail (English speakers in the Walker et al. study performed at chance in both same (46%) and different (43%) conditions).[2] Although this outcome is consistent with an account in which verb-focused word learning biases children toward relational solutions, it is also possible that Mandarin speakers succeed at the task for more general reasons (attention, etc.), without having a relational bias.

We can discriminate these two possibilities by examining bias in an ambiguous task, with both relational and object matches available, and no definitive correct answer. If Mandarin-speaking toddlers succeeded in Experiment 1 because of a general aptitude for test-taking, and not a specific bias toward relations, then they should respond at chance in a modified RMTS with no correct answer. Additionally, if an object bias is responsible for the poor performance of English speakers (and not just random responding), then we should observe systematic preferences for object matches when there is no conflicting evidence for relations. In Experiment 2, we assess these possibilities.

Experiment 2: Comparing relational and object focus across cultures

Experiment 2 tests for baseline differences in bias toward relational or object-based hypotheses across Mandarin and English speakers. To do this, we created an ambiguous paradigm, in which it is unclear whether a particular object or the relationship between objects is causal. Specifically, we presented children with a "different is causal" condition, in which the same object appears in each of the causal pairs (see Figure 3). In this case, it is perfectly reasonable to infer that either the individual object (i.e., the blue square) or the relation (i.e., different) produced the effect. We pit these options against each other by presenting the same objects in the test pairs. The individual objects come together to create a "same" pair—which is correct with respect to the object hypothesis, but incorrect with respect to the relational hypothesis, and the other objects associated with the effect come together to create a "different" pair—which is correct with respect to the relational hypothesis and incorrect with respect to the individual object hypothesis.

If a focus on verbs in early language learning induces a bias toward relational hypotheses, we should observe a tendency toward relational solutions in Mandarin-speaking toddlers, and a converse bias toward objects in noun-focused English-speaking toddlers.

Methods

Participants. A total of 112 3-year-olds participated in Experiment 2, 56 native Mandarin speakers (M = 41.4 months; 28 female) and 56 native English speakers (M = 41.4 months; 21 female). An additional 11 children were tested but excluded as a result of experimenter error or failure to complete the study. Mandarin-speaking children were recruited and tested at preschools in China, and English speakers at preschools and museums in the U.S. In all settings, children were tested individually with the experimenter in a private room.

Materials and procedure. Materials were identical to those in Experiment 1, and the procedure closely resembled that of the "different" condition, but with several modifications to create an ambiguous causal structure (see Figure 3).

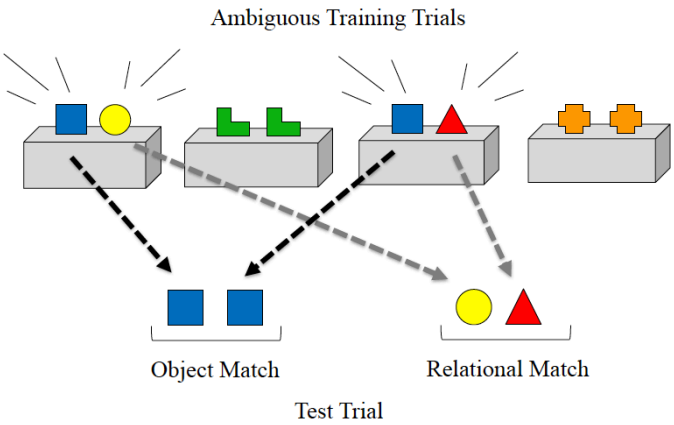

Figure 3: Schematic illustration of ambiguous training and test trials in Experiment 2, in which the evidence was consistent with both object and relational solutions.

First, one of the blocks (represented by the blue square in Figure 3) appears in *both* different pairs. This reoccurring block provides the object-based hypothesis (i.e., the blue

[2] We compared performance of Mandarin-speaking preschoolers in the current study with English-speaking preschoolers in Walker et al. (2016). Considering each condition separately, we find a significant difference between Mandarin- and English-speaking preschoolers in the *different* condition (one-tailed p = .022, Fisher's exact) and a marginal difference in the *same* condition (one-tailed p = .068, Fisher's exact). Combining across *different* and *same* conditions, we find that Mandarin-speaking preschoolers significantly outperform English speakers (one-tailed p = .004, Fisher's exact).

square is causal). Second, the test trial included two pairs composed of blocks that were previously observed in the "different" training pairs. Finally, due to the constraints of the study design, it was not possible to present an ambiguous *same* condition. As a result, Experiment 2 only included the *different* condition. As in the previous study, the experimenter asked the child to choose the pair that would activate the machine. The child's first point or reach was scored as consistent with either an object selection or a relational selection.

Results and discussion

Given an ambiguous choice between object and relational matches, English-speaking preschoolers selected the object match (64%; two-tailed binomial $p = .044$) and Mandarin-speaking preschoolers chose the relational match (66%; two-tailed binomial $p = .022$; see Figure 4).

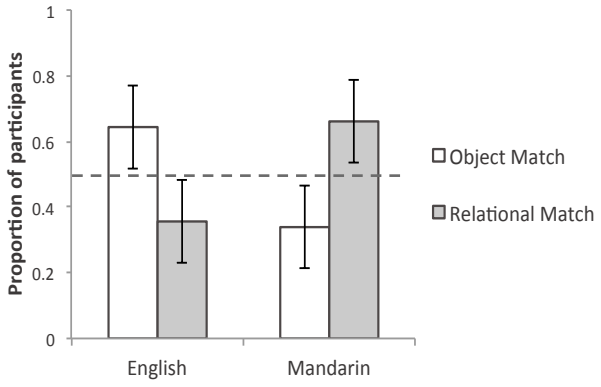

Figure 4: Proportion of object and relational matches selected by English- and Mandarin-speaking toddlers in Experiment 2. Error bars indicate 95% confidence intervals.

General discussion

In two experiments, we find that Mandarin-speaking children tend to privilege relations whereas English-speaking children tend to privilege individual objects, often missing the abstract relation.

In Experiment 1, we evaluated whether the noun focus in English word learning can account for the dip in relational reasoning observed in English-speaking preschoolers. To do so, we examined relational reasoning in Mandarin-speaking preschoolers, whose early language learning is more focused on verbs. Consistent with the noun-focus account, we found that Mandarin-speaking preschoolers substantially outperform their English-speaking peers in identifying shared relational structure in the RMTS.

In Experiment 2, we tested for the key factor predicted to mediate the relationship between language and RMTS performance. This study explored whether English- and Mandarin-speaking preschoolers exhibit differing biases toward relational and object-based solutions. Indeed, we found that in an ambiguous context with no correct answer, Mandarin speakers tend to favor solutions consistent with relational hypotheses and English speakers show a contrasting object bias.

It is important to note that while English-speaking preschoolers have often exhibited poor performance in relational tasks of the same format, their consistent selection of object-based matches in this experiment is not trivial. Choosing the object match may indeed present a more challenging cognitive task. In order to select the object match at test, children must track and remember the relevant object (the blue square) throughout the training trials, which (perhaps counterintuitively) increases the cognitive load compared with learning the abstract relation, which does not require tracking of any particular objects. Accordingly, this outcome demonstrates a surprising competence on the part of English-speaking preschoolers, which may also be attributable to their noun-centric language learning.

Taken together, these findings inform potential sources of bias in early learning and the development of relational reasoning. In particular, they rule out the possibility that language learning in general produces an object bias. Instead, we show that preschoolers of the same age in different linguistic and cultural contexts may have varying degrees of relational and object focus, and that these differences correlate with robust population-level differences in relational reasoning.

Our findings stand in contrast to the suggestion that language plays a paradoxical role in relational development, by both hindering relational reasoning and facilitating it (Hoyos et al., 2016). Although this may be true in noun-focused languages, like English, it does not appear to be a general feature of language learning.

Furthermore, we suggest that language may well act to hinder *and* facilitate relational reasoning, without the need to view this phenomenon as a paradox. Instead, it is possible that the object bias and the associated dip in relational reasoning observed in English speakers result from general learning processes with no exceptional role for language. Instead, the structures and features of language may be interpreted as some of many sources of input informing the types of concepts that are privileged during early learning.

Of course, several questions remain regarding the source of the population differences observed here. For example, it is certainly possible that cultural factors (other than language) play a role in facilitating a relational focus in Mandarin speakers. Indeed, there are well-documented differences between collectivist and individualist cultures, which may similarly result in an emphasis on relationships *between* entities or on characteristics of individual entity kinds (e.g., Chiu, 1972; Choi, Nisbett, & Norenzayan, 1999; Nisbett, Peng, Choi, & Norenzayan, 2001; Oyserman & Lee, 2008; Peng & Knowles, 2003). Our ongoing research is aimed at further pulling these hypotheses apart.

That said, regardless of whether language, culture, or some combination of the two is ultimately responsible for these effects, the current findings demonstrate that preschoolers have the *capacity* to infer relational properties, providing additional evidence that the object bias is learned after early competence in relational reasoning is achieved

(Walker et al., 2016). More broadly, we have established population-level differences in relational focus that occur naturally across cultures early in development and predict the developmental trajectory of relational reasoning.

Acknowledgments

We thank Gail Heyman, Kang Lee, Jing Zhang, Caitlyn Lanigan, and Amy Zou for invaluable assistance with data collection. This work was supported by the Ammodo KNAW Award and the NSF Graduate Research Fellowship Program under grant DGE 1106400 to AC.

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