Context shapes early diversity in abstract thought

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Early abstract reasoning has typically been characterized by a "relational shift," in which children initially focus on object features but increasingly come to interpret similarity in terms of structured relations. An alternative possibility is that this shift reflects a learned bias, rather than a typical waypoint along a universal developmental trajectory. If so, consistent differences in the focus on objects or relations in a child's learning environment could create distinct patterns of relational reasoning, influencing the type of hypotheses that are privileged and applied. Specifically, children in the United States may be subject to culture-specific influences that bias their reasoning toward objects, to the detriment of relations. In experiment 1, we examine relational reasoning in a population with less object-centric experience—3-y-olds in China—and find no evidence of the failures observed in the United States at the same age. A second experiment with younger and older toddlers in China (18 to 30 mo and 30 to 36 mo) establishes distinct developmental trajectories of relational reasoning across the two cultures, showing a linear trajectory in China, in contrast to the U-shaped trajectory that has been previously reported in the United States. In a third experiment, Chinese 3-y-olds exhibit a bias toward relational solutions in an ambiguous context, while those in the United States prefer object-based solutions. Together, these findings establish population-level differences in relational bias that predict the developmental trajectory of relational reasoning, challenging the generality of an initial object focus and suggesting a critical role for experience.

cognitive development | relational reasoning | learning | culture

The ability to engage in relational reasoning is often cited as a defining feature of human cognition (1). Nevertheless, decades of research reports that young learners tend to struggle with relational abstraction (e.g., ref. 2). According to the prevailing view, this is because children's early similarity judgments are dominated by shared object properties and surface features. Then, over the course of development, they expand their understanding of similarity to include relational information (i.e., the "relational shift"; e.g., refs. 3–5).

In contrast, recent evidence suggests that the foundations for relational reasoning are in place much earlier than previously believed (6–9). In particular, preverbal infants (3 to 9 mo, depending on the task) distinguish the relations "same" and "different," looking longer at novel pairs of objects that differ from the habituated relation (6, 10). There is also extensive evidence for early recognition of relational patterns at this age (e.g., refs. 11–14). Even stronger evidence has been found in toddlers (18 to 30 mo), who infer these abstract concepts in a causal version of a relational reasoning task (i.e., matching AA′ with BB′, not CD, and matching EF with CD, not BB′; see Fig. 1 and refs. 8, 9, and 15) and apply them in generating novel actions. How might we resolve the apparent conflict between this early relational competence and the decades of research documenting the relational shift?

According to the relational shift account, relational reasoning is a hallmark of general cognitive development. In this view, the acquisition of relational categories marks a key developmental change in domains of knowledge that are initially built upon perceptually driven concepts. As a result, this account has focused on the emergence of relational competence over the course of development, which is supported by the acquisition of domain-specific content knowledge (3, 4, 16), relational language (e.g., ref. 17), and the maturation of domain-general factors, like executive function (18, 19). This initially intuitive idea—that early learning must progress from the concrete to the abstract—extends as far back as Piaget (20). However, a strict interpretation of the relational shift account has recently come under pressure to accommodate growing evidence of early relational competence (6–15, 21, 22). An alternative response to these recent challenges draws on Bayesian accounts of the "blessing of abstraction" (i.e., hierarchical Bayesian models; ref. 23) and corresponding empirical research (24–26), which suggests that children's ability to infer object-based and relational concepts likely develops more or less in tandem. Based on this evidence, the rational learner account (15) proposes that a child's tendency to select relational or object-based solutions has little to do with domain-specific knowledge or general cognitive maturity, and instead depends upon the probability assigned to each type of hypothesis in a given context.

Key differences between these accounts are highlighted in their distinct explanations of a recent empirical puzzle: the apparent decline in relational reasoning during early development. Specifically, while 18- to 30-mo-olds successfully infer same–different relations in the simple causal relational reasoning task described above (Fig. 1), 3-y-olds fail (15). Similar difficulties have been observed in 3-y-olds across a variety of related relational reasoning tasks (e.g., refs. 3, 17, and 27–28). Then, around 4 y of age, children again succeed in the standard relational match-to-sample (RMTS) task (17) but continue to neglect relational similarities in other contexts, even at 5 to 6 y of age (e.g., ref. 3). 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 improvement, as previously

Significance

An influential view of early learning holds that children tend to focus on surface features of objects, before undergoing a "relational shift" toward perceiving structured relations between items. However, this developmental trajectory may reflect a learned bias occurring selectively in cultural contexts that promote object-centric thinking. We find that 3-y-olds in China succeed in a relational task that their US counterparts fail and provide evidence for different developmental trajectories across these distinct learning contexts. Three-year-olds in China also tend to privilege relational solutions in an ambiguous task, whereas those in the United States privilege object-based solutions. These differences suggest distinct biases in abstract thinking and imply that the development of abstract thought is more context-sensitive than previously thought.

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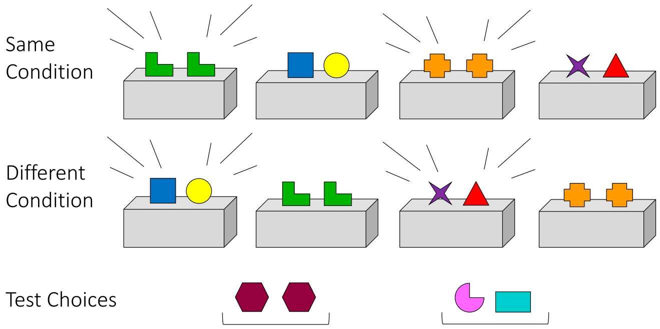

Fig. 1. Schematic illustration of training for each condition (top two rows) and test trials (bottom row) in experiments 1 and 2.

suggested (e.g., ref. 29). What causes this curious dip in performance around 3 y of age?

The Relational Shift "Paradox" Perspective. According to Hoyos et al. (30), older children may fail because of a temporary object bias that is induced by avid noun learning. The authors provide evidence consistent with this view, in which an experimentally induced noun bias interferes with RMTS performance in 4-y-olds, who otherwise succeed. They suggest that language learning—and an emphasis on nouns in particular—may negatively impact relational reasoning in 3-y-olds. They note, however, that earlier work (17) leads to the opposite conclusion: that the use of linguistic concepts—in this case, relational nouns—facilitates relational reasoning. In particular, Christie and Gentner (27) suggest that children may not initially have access to a sufficient hypothesis space that includes relational meanings, and instead form new relational hypotheses when prompted to compare colabeled items. Together, these findings create what Hoyos et al. (30) term "the paradox of relational development," in which some features of language acquisition orient learners away from relations, while others provide critical scaffolding to support relational learning. In other words, experience with language learning appears to solve the very problem it creates.

The Rational Learner "Paradigm" Perspective. According to the rational learner account, even very young children have—and retain—genuine same–different concepts (9) but tend to neglect relational information as a result of a learned bias to attend to objects and their properties (15). This claim is consistent with evidence that preschool-aged children attend to objects and attributes (e.g., refs. 4, 17, 27, and 31) but treats this attention as preferential—an optional learned bias, rather than a typical waypoint on the standard developmental trajectory. Importantly, this computational-level account remains agnostic about the origins of these relational representations and the processes (or algorithms) by which these representations arise (e.g., innate, structure mapping). What it does predict, however, is that differences in a learner's experience could lead to differences in which type of existing hypotheses are privileged and ultimately applied. Accordingly, any input that changes the distribution of prior expectations over a learner's hypothesis space (linguistic or otherwise) can influence children's inferences. In this view, consistent differences in the focus on objects or relations in a child's learning environment could create distinct developmental paradigms of relational reasoning, only some of which are U-shaped.

This alternative view draws on probabilistic models of cognitive development, in which children are seen as Bayesian learners who weight the likelihood of a given hypothesis (the probability of the data given the hypothesis) by its prior probability (the probability of the hypothesis before data are observed; ref. 32). Consequently, if a hypothesis has high prior probability, it will require stronger evidence to overturn it. This reasoning may also be applied to entire categories of hypotheses in the form of an overhypothesis, or general principle by which the learner assigns higher prior probability to particular types of hypotheses over others (23, 33). From this perspective, the "noun explosion" in early language learning could be one of several forms of input that lead to the formation of an overhypothesis that temporarily privileges object-based hypotheses over relational ones (for a discussion of language-induced overhypotheses and their relevance beyond language see ref. 34).

Environmental Variation as a Driver of Children's Hypotheses. If the dip in relational reasoning reflects an object bias that is shaped by early experience and incidental to the overall developmental trajectory, then it need not be a universal feature of early childhood. Instead, the observed U-shaped performance could be an artifact of culture-specific learning environments that promote a focus on object-based hypotheses through object-centric experience. In this case, developmental conclusions about relational reasoning may be unique to—for instance—WEIRD (Western, educated, industrialized, rich, and democratic; ref. 35) samples, in which there are well-documented emphases on decontextualized objects (36) and noun learning (37). By examining the emergence of relational reasoning in populations that receive different culture-specific input, it is possible to examine the potential role of contextual factors on the developmental trajectory of relational reasoning.

Indeed, prior work has already begun to capitalize on these differences and provides initial evidence for variance in relational reasoning across contexts, although there is no clear consensus regarding the mechanism underlying these effects (18, 38, 39). Notably, Kuwabara and Smith (38) found that 4-y-olds in Japan outperform 4-y-olds in the United States on RMTS and proposed that this difference may be driven by a Japanese cultural bias to attend to relations. Richland et al. (39) found a similar advantage when comparing analogical reasoning between 3- and 4-y-olds in Hong Kong and the United States on a picture-mapping task and proposed that this difference is driven by greater inhibitory control among children in Hong Kong. While these findings are suggestive, the differences reported between groups are differences in the degree of success, based on children's overall performance. Could variation in the learning environment produce qualitative differences in performance across contexts, leading—as the rational learner account predicts—to distinct developmental paradigms? Or, do environmental factors merely modulate a common trajectory—that is, the relational shift—which unfolds similarly across groups (despite differences in timing)?

In an effort to further explore and extend these existing cross-cultural findings, the current research investigates the magnitude to which environmental variation (broadly construed) may influence the developmental trajectory of relational reasoning. To do this, we compare a context in which the culture-specific learning environment highlights objects and object features (English speakers in the United States) to another context highlighting relational structure (Mandarin Chinese speakers in China). For English learners in the United States, a cultural focus on objects (36, 38) and linguistic focus on learning nouns (30, 37) may direct children's attention to objects and object properties. Conversely, Mandarin learners in China may be subject to an emphasis on relations that is characteristic of some East Asian cultural contexts (38, 39) and a linguistic bias toward verbs rather than nouns (40, 41), which could direct their attention toward relations. Accordingly, the variation between these culture-specific learning environments presents two natural conditions with which to examine the role of contextual factors on the development of relational reasoning. We return to consider these and other potential factors in the *General Discussion*.

To preview our results, in experiment 1 we find that 3-y-olds in China successfully apply same–different relations in the causal relational reasoning task, while 3-y-olds in the United States perform at chance. In experiment 2, we provide further evidence for these differences by examining the developmental trajectory of relational reasoning performance in Chinese children between 18 and 36 mo. Specifically, we find that Chinese children maintain high performance in relational reasoning, in contrast with previous research in the United States (15), which has found a gradual reduction in performance during this same developmental window. Finally, in experiment 3, we reveal different baseline biases in Chinese and American 3-y-olds, who demonstrate preferences for relational and object-based hypotheses, respectively. This finding confirms a prediction of the rational learner account and provides support for the view that cognitive biases underlie the differences in performance observed across contexts.

Experiment 1: Reasoning in a Relation-Centric Environment

As an initial assessment of culture-specific differences, 3-y-olds in both cultures completed the causal relational reasoning task developed by Walker and colleagues (ref. 8, experiment 2; ref. 15, experiment 1; see Fig. 1). 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 children 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. Children are then shown novel pairs of "same" or "different" blocks and asked to choose which pair will activate the toy; selecting correctly requires that children pick the pair that is relationally consistent with their training.

Based on the results from previous research, we hypothesized that 3-y-olds in the United States would respond at chance, failing to infer the abstract same–different relations at test. If 3-y-olds in China spontaneously succeed on this same task, this would demonstrate cross-cultural variability in the expression (success vs. failure) of relational reasoning, support previous accounts of early relational competence, and provide a cultural testbed in which to evaluate determining factors in the developmental trajectory.

Results. As predicted, Chinese children consistently selected the relational pair at an age at which their US counterparts fail to do so. Three-year-olds in the United States performed at chance in both same (20/38 correct; two-tailed binomial, $P > 0.1$) and different (15/38 correct; two-tailed binomial, $P > 0.1$) conditions, replicating previous findings (8, 15). In contrast, 3-y-olds in China correctly selected the test pair that was consistent with their training in both same (28/39 correct; two-tailed binomial, $P < 0.01$) and different (28/38 correct; two-tailed binomial, $P < 0.01$) conditions. Comparing performance across cultures, we find that Chinese children significantly outperform children in the United States (two-tailed $P < 0.01$, Fisher's exact) in inferring same–different relations.

Experiment 2: Evidence for Distinct Developmental Trajectories in Reasoning Across Contexts

The differences in performance reported above might indicate distinct developmental trajectories of relational reasoning. If so, this would suggest that early biases toward objects or relations are indeed learned, and therefore likely to be sensitive to differences in the learning environment. Alternatively, children in both groups may follow the same pattern of development, with 3-y-olds in China lagging (performing similarly to 18- to 30-mo-olds in the United States) or leading (performing similarly to 4-y-olds in the United States) in the same general trajectory. To tease these possibilities apart, experiment 2 examines the development of relational reasoning in Chinese children from 18 to 36 mo—assessing the 1.5-y window before the age assessed in experiment 1. Given the decline in relational reasoning between 18 and 48 mo in the United States (15), a common trajectory account would predict a parallel (albeit offset) decline in Chinese children, which would likely appear within this 18- to 48-mo window.*

Results. Findings of experiment 2 provide evidence for a distinct developmental trajectory of relational reasoning in China, compared with previous work conducted in the United States (ref. 15 and Fig. 2). We ran a binomial logistic regression using age (in months), cultural context (United States, China), and condition (same, different) to predict the likelihood of correctly selecting the relational response. Cultural context was a significant predictor ($\beta = 3.27$; $P = 0.05$[†]), and there was a significant interaction of cultural context and age ($\beta = -0.11$; $P = 0.01$), such that accuracy decreased over the 18- to 48-mo window for children in the United States but was

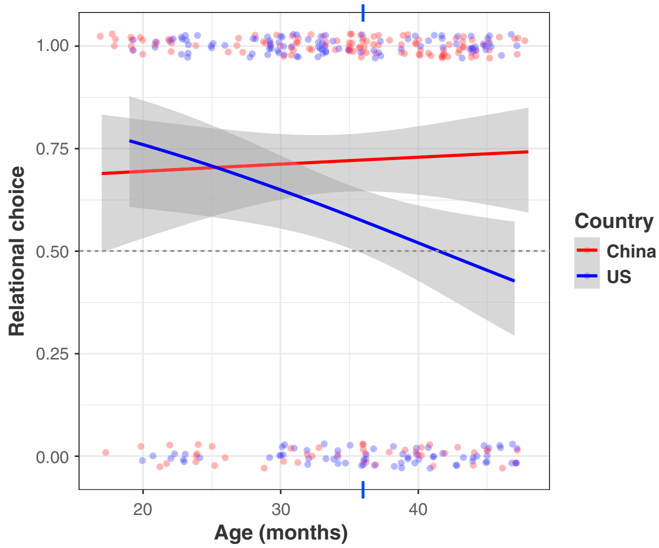

Fig. 2. Relational match (1) and nonmatch (0) options selected by 18- to 48-mo-olds in the United States and China in experiments 1 and 2, plotted with logistic regression fit lines. US toddler data (blue dots left of the indicator lines at 36 mo) are from Walker et al. (ref. 15, experiment 1). Shaded regions indicate 95% confidence intervals with Loess smoothing.

maintained for those in China, as shown in Fig. 2. There were no other significant main effects or interactions (but see *SI Appendix* for additional analyses considering performance by condition and age). These findings therefore provide support for distinct paradigms of relational reasoning across contexts.

Experiment 3: Comparing Object and Relational Focus Across Contexts

Although the results of experiments 1 and 2 are consistent with an account in which contextual factors influence whether children privilege the relational hypothesis, these findings may also be due to domain-general differences between groups (e.g., executive function, general attention, motivation, and aptitude; e.g., refs. 18, 19, 38, 42, and 43). In experiment 3, we discriminate among these possibilities by testing for baseline differences in bias toward relational or object-based hypotheses that are predicted to underlie the differences in performance reported above. Specifically, 3-y-olds in both cultures were offered a forced choice between a relational and object-based solution in an ambiguous formulation of the causal relational reasoning task in which both hypotheses are supported by the evidence observed. If the cross-cultural difference reported in experiments 1 and 2 results exclusively from differences in general aptitude, with no contribution of a bias toward objects or relations, then we should find no difference in selections across cultures. If, however, culture-specific features of the learning environment induce a cognitive bias, we should observe a systematic preference for relational solutions in China, and a converse preference toward object-based solutions in the United States.

Children were presented with a different condition, in which one particular object from the initial causal pair appears again in the second causal pair (refer to Fig. 3). In this case, it is reasonable to attribute causality to either the recurring object (e.g., the blue cube) or the relation (i.e., different). Indeed, previous research with younger US toddlers using the same training trials indicates that they have no difficulty selecting the appropriate match when given unambiguous test choices (i.e., between two relations or two objects), demonstrating that 18- to 30-mo-olds successfully infer both solution types (44). In this case, however, training pairs were recombined to form an ambiguous choice between the test pairs. Specifically, two instances of the recurring object came together to create a "same" pair—which is correct with respect to the object hypothesis but incorrect with respect to the relational hypothesis. The other objects associated with the

*In principle, a temporal offset for children in China could also result in a decline in relational reasoning performance occurring earlier or later than this 18- to 48-mo window (see *General Discussion* for a review of this alternative).

†The estimated coefficients (β) are interpretable as log odds but can also be transformed to an odds ratio ($OR = e^{\beta}$).

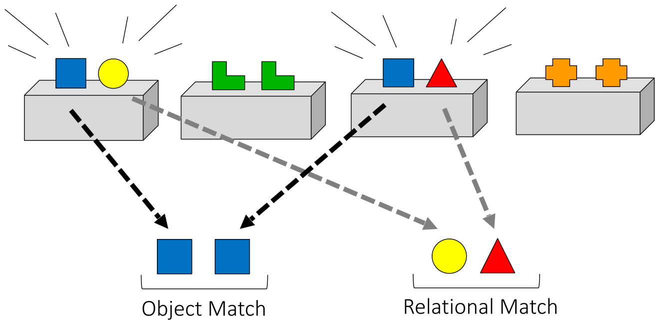

Fig. 3. Schematic illustration of ambiguous training trial (top row) and test pairs (bottom row) in experiment 3, in which the evidence was consistent with both object and relational solutions.

effect also came together, to create a "different" pair—which is correct with respect to the relational hypothesis and incorrect with respect to the object hypothesis.[‡] Due to the constraints of the study design, it was not possible to present an ambiguous same condition, and, as a result, we only include a different condition in experiment 3.

Results. Given an ambiguous choice between object and relational matches, 3-y-olds in the United States selected the object match (36/56; two-tailed binomial, $P = 0.04$), while 3-y-olds in China selected the relational match (41/60; two-tailed binomial, $P < 0.01$). As predicted, we also find a significant difference between groups (two-tailed $P < 0.01$, Fisher's exact; Fig. 4).

General Discussion

In three experiments, we find that young children in China—unlike their counterparts in the United States—tend to privilege abstract same–different relations in a causal learning task. In experiments 1 and 2, children in China were significantly more likely to identify relational structure and showed no evidence of a decline in reasoning between 18 and 48 mo. In experiment 3, we tested for the key factor predicted to mediate these differences, assessing whether children across contexts exhibit distinct biases to privilege either relational or object-based solutions. Indeed, we found that in an ambiguous task with no correct answer, Chinese 3-y-olds favored solutions consistent with the relational hypothesis, while those in the United States favored solutions consistent with the contrasting object bias. Together, these findings suggest that culture-specific learning environments may bias the early development of relational reasoning to follow different developmental trajectories.

On the other hand (as noted above), it is conceivable that the U-shaped trajectory of relational reasoning previously observed in the United States indeed reflects a cognitive universal, occurring at a sizable temporal offset for children in China. Given that the regression analysis reported in experiment 2 shows no evidence of a decline in relational reasoning between 18 and 48 mo in China, the downward slope would have to occur either after 48 mo or well before 18 mo (to allow performance to recover). However, given that the first evidence of children's ability to infer and act on specific causal properties from contingency data appears around 16 mo in the United States (46), a decline seems unlikely to occur much earlier than 18 mo. Alternatively, cross-cultural differences in domain-general factors like executive function could drive a lag in performance and corresponding later decline in relational reasoning in Chinese children. However, this explanation is at odds with existing findings demonstrating that preschoolers in both China and Hong Kong outperform their American counterparts in tasks with high executive function demands (39, 42, 43). Indeed, variation in general cognitive maturity is an unlikely explanation for the observed differences in this task, given that 18- to 30-mo-olds outperform their 3-y-old peers in the United States, despite having comparatively fewer cognitive resources (15). Other culture-specific differences could also account for a lagging decline in China, but this too seems unlikely given the advantages in relational reasoning observed for older children in some other East Asian cultural contexts, including 3- and 4-y-olds in Hong Kong (39) and 4-y-olds in Japan (38). Therefore, when considered in light of the previous research, these data most likely indicate truly distinct developmental trajectories, shaped by substantive variation across culture-specific learning environments.

This cross-cultural diversity informs potential sources of bias in the development of relational reasoning in particular and early learning in general. That is, children of the same age in different learning environments may have varying degrees of relational and object focus, and these differences align with robust population-level differences in the appearance of relational reasoning. This finding rules out the proposal that language learning in general produces an object bias, but is in line with the spirit of Hoyos et al.'s (30) suggestion—that lexical biases may play a role in guiding early relational reasoning. While particular features of the linguistic context may act to either hinder or facilitate relational reasoning, there is no need to characterize this phenomenon as a paradox. Instead, the structures and features of language may simply serve as a subset of the many sources of input (culturally specific or otherwise) informing the hypotheses that are privileged during early learning.

These findings therefore follow one of the key predictions of the more general rational learner perspective, by which systematic variation in relational focus could create distinct developmental paradigms of relational reasoning. Although the current study was not designed to discriminate between the rational learner and relational shift accounts, it does provide evidence against a universal developmental trajectory and may help to explain various inconsistencies in relational ability reported in the existing literature (6–15, 21, 22), including previous cross-cultural findings (38, 39). From this perspective, variation in relational responding results, in part, from variation in the learning environment. While this account does not preclude the possibility of a relational shift, this is only one of many possible learning trajectories supported by the rational learner account and may not generalize across learning contexts.

Several questions remain regarding the specific source of the population differences observed here, and ongoing research is aimed at further pulling these influences apart. For example, which features of the culture-specific learning environment are responsible for the differences in relational reasoning found in the United States and

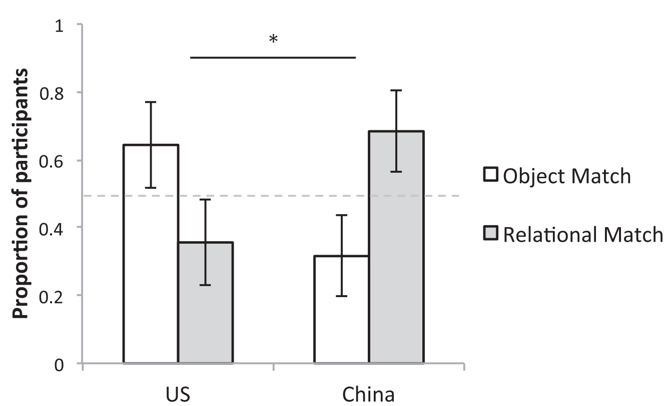

Fig. 4. Proportion of object and relational matches selected by children in the United States and China in experiment 3. Error bars indicate 95% confidence intervals, and the dotted line represents chance performance. Match choice differed significantly between groups (*$P < 0.01$).

[‡]In this task, both the "object match" and "relational match" pairs are composed entirely of objects that were associated with the toy activating in the training trials. Because of this, both test pairs can be interpreted as including an object match, but only one pair serves as a relational match. From an object matching perspective, there is better evidence for the recurring object (i.e., the blue cube in Fig. 3), as this object was present *both times* the toy activated. Previous research from the causal learning literature indicates that preschoolers are sensitive to this type of evidence when making causal attributions (e.g., 45).

China? One possibility (described above, ref. 30), builds on a substantive body of research implicating language in the early development of relational reasoning (e.g., refs. 17, 27, and 30). Specifically, the rapid noun spurt that characterizes early English word learning may induce a temporary bias toward objects and object properties that interferes with relational reasoning (30). However, 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" (47, 48). 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 (40). Relatedly, infants learning Mandarin Chinese show fast mapping of novel labels for actions, but not for objects, while their English-learning counterparts demonstrate no such action advantage, mapping novel labels to both actions and objects (41). If an emphasis on noun learning (relative to other parts of speech) drives disadvantages in relational reasoning by fostering an object bias (30), then children learning a more verb-centric language should show an attenuated or reversed bias. That is, while nouns may direct focus to object properties, verbs often signal relations across multiple entities, and might redirect attention accordingly. Indeed, Gopnik et al. (49) present related evidence for this view in a longitudinal study of Korean infants. They found that children's early use of relational language (verbs in Korean) indicating success or failure (e.g., "an hay" in Korean or "uh oh" in English) was linked to earlier success in means–ends problem solving for Korean children relative to their American peers, who acquire both later in development.

That said, language is just one of many possible sources of input that influence a rational learner's prior expectations, and other cultural factors may also drive a bias toward relational or object-based solutions. In particular, there are well-documented differences in holistic and analytic processing (and relatedly, collectivist and individualist cognitive styles) across cultures, which may similarly result in an emphasis on relationships between entities or on characteristics of individual entities (e.g., refs. 50 and 51). More broadly, environmental variation across these learning contexts (e.g., socioeconomic status, number of siblings, and pedagogical and child-rearing practices; see refs. 52–54) may differentially affect general cognitive skills that are known to influence relational reasoning, like executive function (18, 19, 42). Although our samples were drawn from communities with similar demographics (i.e., urban, middle class neighborhoods near major universities), ongoing research aims to tease apart these possible influences by comparing the development of relational reasoning in more closely matched populations [e.g., northern and southern Italy, where children with a shared linguistic context but variation in culture and social class show corresponding differences in holistic processing (55)].

Regardless of which specific features of the learning environment are ultimately responsible for these effects, the current findings demonstrate that 3-y-olds certainly have the capacity to infer relational properties, providing additional evidence that the observed object bias is acquired after early competence in relational reasoning is achieved (in the United States). Critically, this work demonstrates spontaneous success on same–different reasoning in 3-y-olds. This stands in contrast to previous research, which has concluded that children at this age require additional scaffolding to solve this task (e.g., refs. 15 and 17). Further, we show that early deficiencies in relational reasoning are more likely to result from a difference in tendency, rather than a difference in ability. More broadly, we have established naturally occurring population-level differences in relational focus that appear early in development and predict qualitative differences in the trajectory of relational reasoning.

Methods

Experiment 1.

Participants. A total of 153 36- to 48-mo-olds participated in experiment 1, including 76 native English speakers [mean (M) = 41.9 mo; 36 female] in the United States and 77 native Mandarin speakers (M = 41.2 mo; 36 female) in China. Sample size satisfies a power analysis with power >0.8, given an alpha of 0.05 and an effect size of 0.3 (medium). An additional three participants were excluded due to experimenter error (1), failure to complete the study (1), or interference by another child (1). All procedures were approved by the Institutional Review Board at the University of California, San Diego (UCSD) (151866) and informed consent was obtained for all participants (experiments 1–3). Toddlers in the United States were recruited and tested at preschools, museums, and in the laboratory at UCSD (with comparable performance across testing locations) and toddlers in China were recruited and tested at preschools. Both samples were composed of children living in large cities, recruited in and around major universities (UCSD in La Jolla, CA and Zhejiang Normal University in Jinhua, Zhejiang Province). We did not collect specific demographic information. However, participants were recruited from institutions serving middle-class urban communities. Additionally, Chinese participants were likely only children, owing to Chinese family-planning policies. Half of the children in each group were randomly assigned to same or different conditions. In all settings, children were tested individually in a private room.

Materials and procedure. The materials and procedure replicated Walker et al. (ref. 15, experiment 1), with the exception that instructions for Chinese participants were given in Mandarin Chinese. The original English instructions were independently translated and back-translated by English–Mandarin bilinguals in China and the United States to ensure accuracy. Different experimenters (residents of each country and native speakers of the testing language) performed the task in the United States and China, following the same procedures and training, and were blind to the specific cross-cultural predictions motivating the study design.

Children were seated at a table across from the experimenter. Before beginning the task, the experimenter led the child in a brief warm-up activity, which involved interacting with several small toys and served to familiarize the child with the experimenter. After this, the experimenter placed a total of four pairs of same and different painted wooden blocks (two pairs of each relation) on top of an opaque cardboard box, which appeared to activate and play music in response to some pairs of blocks but not others. In fact, the experimenter activated a wireless doorbell inside the box by surreptitiously pressing a button. Depending upon their condition, children either observed evidence that same or different pairs were causal. Then, at test, all children were presented with two new pairs—one same, one different—and asked to point to the pair that would make the toy play music. The experimenter recorded children's first point or reach. A schematic of the procedure for experiment 1 appears in Fig. 1; however, the order of presentation of all blocks was randomized and the side of presentation of the test pairs was counterbalanced. See *SI Appendix* for a detailed script of the procedure.

Experiment 2.

Participants. A total of 80 Chinese toddlers participated in experiment 2, all of whom were native Mandarin speakers tested in China. Each group of toddlers included 40 participants, with toddlers in the younger group aged 18 to 30 mo (±1 mo; M = 23.1 mo; 15 female) and those in the older group aged 30 to 36 mo (±1 mo; M = 33.1 mo; 20 female). Sample size was matched to the US data reported in Walker et al. (15). An additional three children were tested but excluded as a result of experimenter error (1) or failure to complete the study (2). Recruitment and populations were the same as those for Chinese participants in experiment 1.

Materials and procedure. Materials and procedure were identical to experiment 1.

Experiment 3.

Participants. A total of 116 3-y-olds participated in experiment 3, including 60 native Mandarin speakers in China (M = 41.0 mo; 31 female) and 56 native English speakers in the United States (M = 41.4 mo; 21 female). An additional 12 children were tested but excluded as a result of experimenter error (9), failure to complete the study (1), or parent interference (2). Recruitment procedures and populations were the same as those used in experiment 1, except that US toddlers were recruited at preschools and museums and not in the laboratory at UCSD.

Materials and procedure. Materials were identical to those used in experiment 1, and the procedure closely resembled the different condition, but with the modifications illustrated in Fig. 3 to create an ambiguous causal structure, presenting evidence for both relational and object-based hypotheses. To accomplish this, one particular block (e.g., the blue cube in Fig. 3) was repeated in both activating different pairs. At test, children chose between two possible solutions: (*i*) a "same" pair including the object match (e.g., two blue cubes) or (*ii*) a "different" pair that follows the relational rule by combining the two blocks that were previously associated with the effect (e.g., the yellow sphere and red pyramid in Fig. 3). This design presented children with a forced choice between an object match and the relational match.

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