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Characterizing the development of relational reasoning in India

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Abstract

Relational reasoning is an important component of abstract thought that emerges early in development but shows substantial variation across contexts, with children in the US and China following distinct developmental trajectories in one paradigm between 18m and 4y. To understand the mechanisms through which variation in the learning environment influences the development of relational reasoning, we examine early relational reasoning in Punjabi speakers in India, who share some cultural and linguistic elements of their experience with children in both the US and China. In a causal relational match-to-sample task, we find that 3-year-olds in India exhibit performance that is intermediate to their high-performing peers in China and the relatively poor performance observed in the US at this age. These results suggest complexity and variability in the development of relational reasoning and lay a foundation for future research designed to tease apart the factors associated with early diversity in relational reasoning.

Keywords: cognitive development; relational reasoning; culture; language; variation

Relational reasoning and cultural context

How do children come to reason abstractly, transcending their immediate sensory experiences to think in terms of categories that are not perceptually apparent like *snack*, relations like *sister*, or similarity that is structural rather than featural, like seeing a hermit crab's shell as a *house*? One of the most influential perspectives on the development of abstract thought is the relational shift (e.g., Gentner, 1988). On this view, children's initial understanding of similarity is perceptually driven, based on shared features and, with experience, *shifts* to encompass relational similarity as well. However, recent studies have found cross-cultural differences in early relational reasoning (e.g., Richland et al., 2010, Kuwabara & Smith, 2012), and evidence that children in some cultures may follow different developmental trajectories in their early reasoning about similarity (Carstensen et al., 2019).

Specifically, Carstensen et al. (2019) find support for a relational shift, with linear improvement over time, in Chinese children between 18 months and 4 years on a causal relational match-to-sample task. Meanwhile, American children in the same task follow a U-shaped trajectory, performing above chance at 18 months, decreasing to chance between 3-4 years, and improving thereafter. In addition to documenting these cross-cultural differences in the early trajectory of relational reasoning, Carstensen et al. show that the differential performance observed in 3-year-olds is accompanied by complementary biases in reasoning: Chinese preschoolers, who perform well in the relational reasoning task, also prefer relational solutions in an ambiguous context, while American preschoolers prefer object-based solutions instead. These differences in bias, together with the different developmental trajectories of performance observed in this study, suggest that the development of relational reasoning is influenced by the environment in which children grow up.

But what are the critical environmental factors? In particular, what causes the decline in relational reasoning performance observed among children in the US? And why isn't this decline observed in China? There is currently no consensus explanation, with a range of accounts implicating differences in language (Hoyos et al., 2016; Carstensen et al., 2019), executive function (Richland et al., 2010), attention (Kuwabara & Smith, 2012), and social reasoning (Duffy et al., 2009) to explain early differences in relational reasoning between the US and several East Asian populations (specifically, mainland China, Hong Kong, Japan). The common thread across all four of these accounts is that children from East Asian cultures (and particularly speakers of Chinese languages in the language account) show an early propensity for reasoning in context, attending to and incorporating information that is more spatially and temporally distributed than their peers in Western cultural contexts. For example, it may be that increased attention to visual context, like the background of a scene, promotes children's relational reasoning in East Asia by helping them focus on relations between objects instead of the objects themselves. Accounts implicating social reasoning suggest a similar differential attention to context, but driven by social factors like interdependence rather than visual mechanisms, whereas the executive function account emphasizes better performance in attending to such information. These factors are not mutually exclusive, and likely complement each other in explaining developmental variation, perhaps to lesser and greater extents depending on the cultural context (reviewed in more detail in the discussion).

Ultimately, the majority of these accounts (excluding the language account) make similar predictions within East

Asian cultures or those of Europe and North America. To begin to tease apart these accounts, it is crucial to study relational reasoning in cultural contexts outside of canonical East Asian and Western traditions, where developmental differences in executive function, attention, and social reasoning may show less covariance and accordingly be less confounded. India, as a crossroads between East Asian and Western cultural traditions, provides a testbed for such a case study. Here, we assess the early development of relational reasoning by examining the performance of Punjabi-speaking children from India in a causal relational match-to-sample (cRMTS) task, with a narrow focus on development between 3 and 4 years old, the age at which variation in performance is most pronounced in comparisons between children in the US and China.

India shares some historical and structural features with Western Europe and the US, including an educational and political system modeled after that in the UK (Arnove, 1984), and some with China, such as the legacy of a centralized economic system (Sun & Johnston, 2009) and social networks characterized by small, tightly-knit social groups (Grupe & Rose, 2010). In other ways, however, India is unlike both Western and East Asian heritage cultures, with dissimilar indigenous philosophies (a large part of which are based on Hindu as opposed to Greek or Confucian thought; Nakamura, 1964), unique religious systems (Nakamura, 1964; Singh, Huang, & Thompson, 1962), a highly structured caste system (Berreman, 1960), and other distinctive social structures (strong society-oriented values, but with some focus on individuality; Singh, Huang, & Thompson, 1962). Indian culture is also characterized by unique socialization goals, with cultural and parental practices valuing obedience and interdependence while also supporting individual differences and autonomy (Rao, McHale, & Pearson, 2003; Keller et al., 2006) and a strong urban-rural divide (least urbanized and greatest urban-rural disparities relative to the US and China; Mukherjee & Zhang, 2007; Chauvin et al., 2017).

We recruited participants for our study in and around Amritsar in Punjab, a northern state with slightly higher GDP per capita than the national average and a Sikh religious majority. Our participants come from a relatively urban area in a major agricultural region.[1]

The present study

While the United States and China serve as two extreme examples with a stark contrast in language and culture, India, though perhaps more similar to China in several respects, offers a more moderate cultural environment in which to document cRMTS performance in 3-year-olds. Carstensen et al. (2019) suggest that a cultural focus on objects and a linguistic focus on nouns in the US could direct children's attention to objects and their properties at the cost of relational information. At the same time, a converse focus on context and on more relational language (as opposed to nouns, which tend to pick out objects) in China could orient children's attention to relational structure. For Punjabi learners in India, to the extent that there is a more balanced cultural focus on both objects and relations (Mendel et al., 2009; Sinha & Tripathi, 1994), and an intermediate linguistic focus on nouns (Prasad, 2001), these factors may provide for more balanced attention to objects and relations. Accordingly, this experiment affords a test of generality for both the pattern of linear improvement in relational reasoning seen in China, and the U-shaped trajectory characteristic of US performance. Is the unique mixture of cultural features in India associated with one or the other developmental path—or a unique and intermediate one altogether? We examine a relatively narrow developmental window, and accordingly it is beyond the scope of this study to characterize the full arc of cRMTS performance examined in previous work (Carstensen et al., 2019), much less document the many potential co-varying factors. However, this study represents a necessary first step in exploring a wider range of cultural variation in both relational reasoning paradigms and related cultural and developmental factors, in order to elucidate the environmental factors and cognitive mechanisms that shape the development of relational reasoning, a core component of cognition.

Methods

We assess early relational reasoning among Punjabi-speaking 3-year-olds in India using a variation on the causal relational match-to-sample (cRMTS) task from Walker et al. (2016). While cross-cultural variation in relational reasoning has been observed with other paradigms (Richland et al., 2010; Kuwabara & Smith, 2012), we used cRMTS for our study because previously observed cross-cultural variation was most pronounced in this measure, with children from the US and China showing qualitatively different performance (numerically and statistically at or above chance, respectively) on this task between 3 and 4 years of age (Carstensen et al., 2019). Of these cross-culturally varying measures, cRMTS is also the only one documented to show the early success and later decline in performance that make up the U-shaped trajectory observed in the US, and the factors motivating this U-shaped curve are one of several phenomena which we ultimately hope to inform through additional cross-cultural comparisons.

Our methods and analyses were preregistered and are available at https://aspredicted.org/uj5c3.pdf.

Participants Our sample included a total of 76 Punjabi-speaking children between 36 and 47 months old (*M* = 42.7

[1] Punjab is a predominantly wheat-farming state, but rice is commonly farmed during the summer across the region. Talhelm and colleagues (2014) find evidence for a rice-wheat spilt in Chinese culture, where residents of historically rice-farming areas tend toward more interdependent practices and think more holistically than those from wheat-farming areas. While there is some suggestion of a comparable rice-wheat culture split in India (Talhelm et al., 2014; Talhelm, 2019), the evidence is mixed (cf. Von Carnap, 2017).

months; 32f, 44 m). We failed to satisfy our Bayesian optimal stopping criterion (i.e., a Bayes factor of 10 in favor of the test or null hypothesis) with fewer participants, and accordingly followed our preregistered plan to cap data collection at 76 children, as in Carstensen et al. (2019). All participants were native speakers of Punjabi, reported by their parents to primarily speak Punjabi (75% of the time or more), and recruited and tested at preschools in the rural and semi-urban regions of Tarn Taran and Amritsar in Punjab, India.

Procedure Children were tested individually, seated across a table from the experimenter (see Figure 1). All children were tested in Punjabi by a native speaker (T.D.). Before the task began, there was a brief warmup to familiarize the child with the experimenter and with the task of pointing in response to the experimenter's questions.

During the initial training phase, the experimenter placed four pairs—two matching and two mismatched—of painted wooden blocks on top of an opaque box that appeared to play music in response to certain blocks. In fact, the experimenter discreetly activated the music with a wireless doorbell.

Figure 1: A 3-year-old participant selecting a pair of blocks exemplifying the *same* relation in the causal relational match-to-sample task.

To begin the task, the experimenter placed an opaque box on the table and introduced the toy to the child by saying, "This is my toy! Sometimes, when I put things on top of my toy, my toy plays music and sometimes, when I put things on top of my toy, it does not play music. Let's see how it works." The experimenter then presented a causal pair of blocks for the first training trial, said "Let's try!" and put both blocks on top of the toy together while activating the music. She exclaimed "Music!" and once the music stopped playing, the experimenter picked up the blocks, said "Let's try that again!" and repeated the procedure. This time, the experimenter said "*These* ones made my toy play music!" In the second training trial, the experimenter repeated this procedure with a novel inert pair of blocks in the opposite relation (i.e., with a mismatched pair if the first training trial showed a matching pair and vice versa). The experimenter did not activate any music and said "No music! These ones did not make my toy play music." This pattern was repeated for another two training trials with new pairs of blocks (see Figure 2). The experimenter always began with a causal pair of blocks followed by an inert pair, but alternated between causal and inert pairs for the last two training trials.

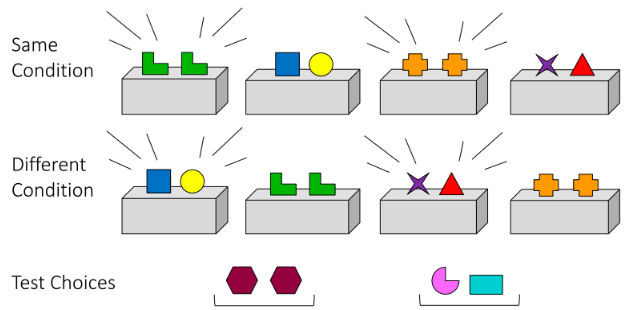

Figure 2: Schematic illustration of the causal relational match-to-sample task (cRMTS) showing training and one test trial. Reprinted from Carstensen et al. (2019).

After four training trials, the experimenter began the first test trial, saying "Now that you know how my toy works, I need your help finding the things that will make my toy play music! I have two choices for you." The experimenter then presented two trays—one with a novel pair of identical blocks and one with a novel pair of non-identical blocks—on either side of the box. Holding up each tray once, the experimenter said, "I have these… and I have these. Only one of these trays has the things that will make my toy play music. Can you point to the tray that has the things that will make my toy play music?" The experimenter recorded the first pair the participant pointed to as the response. Over the next three test trials, the experimenter repeated the same procedure with novel blocks, introducing hand puppets of a dog, a parrot, and a rabbit who needed help choosing blocks to play the music, always following the same relational rule as on the first trial (with same or different pairs causal). The side with the correct pair of blocks was counterbalanced across the four test trials.

After this first set of training and test trials were completed, participants performed a coloring task for one minute while the experimenter stepped out of the room to change the doorbell to a new tune and replace the box with a new one. Upon returning, the experimenter presented the new box by saying, "This is my other toy" and followed the same procedure as in the first four training and test trials except that the causal relation was switched (from *same* to *different* or vice versa).

The materials and procedure were adapted from Carstensen et al. (2019; study 1), with three exceptions: (1) the instructions were given in Punjabi, (2) same and different conditions were run within-subjects as separate blocks (order counterbalanced), and (3) a total of four test trials were conducted per condition. We ran both blocks within-subjects and included four test trials instead of one to maximize data collected during a relatively short field trip, improve our estimates of individual performance, and evaluate an exploratory hypotheses about the potential effects of block and trial order. English instructions were translated and back-translated by two different English-Punjabi bilinguals (the back translator naive to the original script), and the backtranslation was checked against the English instructions and revised to ensure accuracy.

Results

All data and analysis scripts are available at https://osf.io/vmxp6/?view_only=e6715e6a778e48d097f699c51582067b.

Confirmatory analysis Following our preregistration, we used one-tailed t-tests to evaluate whether performance across trials in the *same* or *different* condition was above chance (50%). The 3-year-old Punjabi speakers in our study did not perform above chance in the *same* condition (M = 0.50, $t(76) = 0.16$, p = .4) but did in the *different* condition (M = 0.56, $t(75) = 2.31$, p = .01).

Exploratory analysis We planned and preregistered three exploratory regressions, all of which were run as Bayesian binomial regressions using the BRMS package in R (Bürkner, 2018). The first regression tested for training order effects, evaluating the hypothesis that training first with the same and then different condition facilitates performance in the different condition. The model predicted response as a function of age (in months, centered), condition (same or different), block order (same or different first), and their interactions (all fixed effects). The posterior distribution for each of these effects overlapped with zero in the 95% credible interval (age: β = -0.04, 95% CI = [-0.10, 0.02]), that is, we did not observe any reliable effects.

In our second exploratory regression, we tested for effects of age, condition, and trial number (1-4, per condition), as well as interactions between age and condition, and condition and trial, to evaluate the hypothesis that children will select the relationally correct solution initially and be more likely to (exploratorily) select relationally incorrect solutions on subsequent trials. We also did not find any reliable effects in this analysis (trial: β = 0.11, 95% CI = [-0.10, 0.31]).

Our third exploratory regression examined the relationship between caregiver education and cRMTS performance. We modeled each response as a function of age, condition, their interaction, and caregiver education (coded ordinally). We did not find any reliable effects.

Comparison with US and China data Finally, we conducted an exploratory analyses comparing our data with previous findings in China and the US from Carstensen et al. (2019). Because we found no block or trial order effects in our previous analyses, we included the full data (four trials in each of two conditions) from each child in the India sample for this comparison, though children from the US and China in Carstensen et al. completed only one trial each. We fit a Bayesian binomial mixed-effects model predicting cRMTS performance on each trial as a function of age (in months, centered), condition (same or different), country (India, US, or China), and their interactions, as well as trial (1-4 per condition for Indian participants; always 1 for US and China participants), all as fixed effects. We included random intercepts for each participant. Figure 3 shows performance plotted by country, age, and condition, with 95% credible intervals from this model.

Standard practice with this analysis is to report estimated coefficients (β) and 95% Bayesian credible intervals for effects in which the 95% CIs do not include zero, meaning that there is a 95% chance that the true effect size is nonzero. The only coefficient whose posterior 95% CI did not overlap with zero was for country: China (mean: 73%), with India as the baseline level (mean: 53%), indicating that Chinese participants had higher accuracy than those in India (β = 1.15, 95% CI = [0.21, 2.20]).

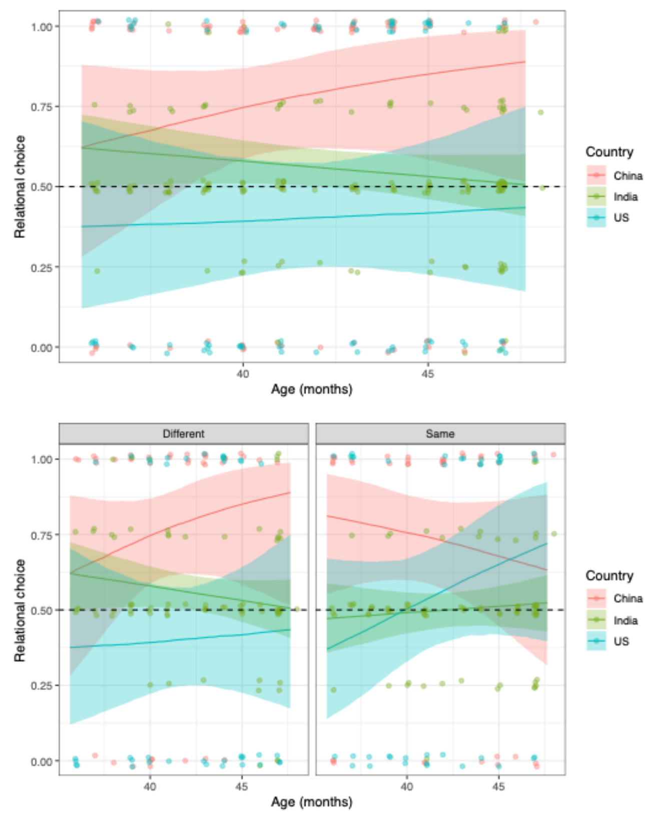

Figure 3: Performance of 3-year-olds in India, China, and the US on cRMTS. Relational match (1) and nonmatch (0) choices are plotted overall (top) and by condition (bottom), with trend lines and 95% Bayesian credible intervals.

Some researchers have suggested that 89% CIs should be used to define notable effects since they provide a more stable estimate of true coefficients, particularly when the effective sample size is below 10,000 (Kruschke, 2014), as it is for all effects in our analysis. By this approach, we would report an additional effect of country: US (mean: 46%) relative to India (β = -0.63, 89% CI = [-1.26, -0.06]), describing better performance among Indian participants than American. We also observe an interaction between condition and country for comparisons between India and the US (β = 0.91, 89% CI = [0.06, 1.71]; see Figure 4).

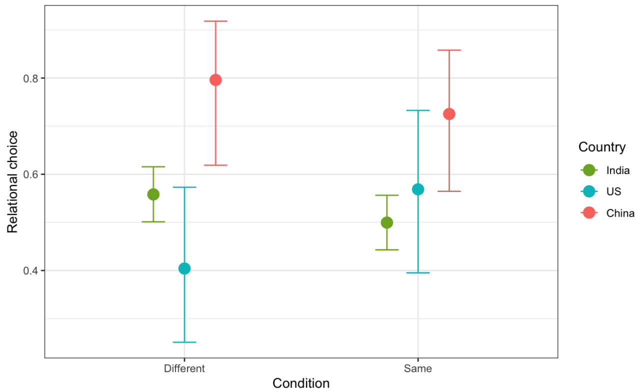

Figure 4: Bayesian coefficient estimates of cRMTS performance for children at 3.5 years old within each sample, with 95% credible intervals (indicating the region where 95% of the posterior draws fall).

Together, these results suggest that performance among 3-year-olds in India is both similar and dissimilar to the US and China. These findings lend support to the trend visible in Figure 3, which shows intermediate performance, overall and in the different condition specifically, for the Indian preschoolers relative to their peers in the US and China.

Discussion

Relative to their Mandarin-speaking Chinese and English-speaking US peers, 3-year-old Punjabi speakers in India exhibited intermediate performance in identifying relational structure in the cRMTS, though additional work is needed to assess whether children in this context follow a different developmental trajectory for relational reasoning.

Although numerically intermediate between children from the US and China, we found only modest statistical evidence distinguishing the Indian children's performance from either. In part this is likely due to our overall level of statistical power, as well as that of the previous study (which had only one trial per participant instead of eight). Although our sample in this study was limited by a brief data collection window, future work will document cRMTS performance with a larger age range, and in relation to measures implicated in accounts of relational reasoning. While the exact nature of 3-year-olds' relational abilities in our sample remains unclear, our findings here suggest a way forward in deconfounding accounts of relational reasoning which argue for multiple facilitating effects in China and decrements in the US.

In the remainder of our discussion, we consider some possible scenarios regarding the development of relational reasoning in Indian children and then turn to factors that might influence this developmental trajectory.

Relational reasoning in India

While we cannot conclude that relational reasoning is comparable in our Indian and American samples, we do observe qualitative similarities. One possibility is that the early trajectory of relational reasoning proceeds similarly for Indian and American children, i.e., following a U-shaped curve, but that this trajectory is shifted slightly earlier for children in India, such that the low point of the U, before the subsequent increase in performance, is seen around 3 years in the US but earlier in India.

Alternatively, it may be that cRMTS performance in India does not follow the U-shaped trajectory observed in the US and there is no decline in performance in India at all. In this case, successful relational reasoning in this task may appear for the first time after age 3 in Indian children, and follow a linear trajectory similar to that seen in China (but with much later emergence). If this is the case, then the trajectories observed in India and China would be most consistent with the relational shift view described by Gentner (1988), in contrast to the U-shaped trajectory seen in the US.

However, it is also possible that children in India do not follow either of these previously established trajectories, and instead follow a third, contextually-dependent developmental path. This outcome, taken together with the US and China findings, would suggest that variation is the norm in developmental trajectories for this task, and perhaps that variation is the norm more broadly in the early development of abstract reasoning. With all possibilities still open, additional research with Indian children from a larger range of ages is needed to document the developmental trajectory in this population, and to elucidate the contextual factors that shape this developmental variation across cultures.

Sources of variation in relational reasoning

While there is clear evidence for variation in early relational reasoning across cultural and linguistic contexts in the cRMTS task, it is much less clear which of the many differences across these contexts shape this variation in the emergence of relational reasoning. Here, we briefly summarize accounts implicating four culturally co-varying factors that could explain variation across India, China, and the US, and review some of the data for each.

Language One account for differences in relational reasoning between the US and China is language learning during early childhood. Language may promote relational reasoning by emphasizing word classes, like verbs, that highlight relational meanings, or hinder it by emphasizing objects instead (Hoyos et al., 2016). English and Mandarin Chinese learners differ in their early lexical bias, and it may be that these differential biases in early language learning can scaffold (in the case of Mandarin verb bias; Tardif, 1996; Chan et al., 2011) or impair (English noun bias; Waxman et al., 2013) relational reasoning, contributing to the differences observed between China and the US.

To our knowledge, there is no work documenting lexical bias in early Punjabi learning, or in closely related languages like Hindi. However, research documenting the child-directed speech of mothers speaking a broad range of Indian languages has found that this speech was roughly balanced with respect to nouns and verbs, or slightly verb-biased (Gogate, Maganti, & Bahrick, 2015). If these findings can be taken as a proxy for early lexical bias in Punjabi, this would suggest that English has the strongest noun bias and Mandarin the weakest (or perhaps a flipped bias in favor of verbs), with Punjabi falling somewhere between the two. Accordingly, if the degree of noun bias in early language learning impairs relational reasoning, we would expect the greatest decrement in English learners, then Punjabi, and the least in Mandarin Chinese learners.

Executive function The maturation of selective attention and related executive functions is also culturally variable, and implicated in relational abilities. Richland et al. (2010) find better analogy performance in Hong Kong Chinese than US preschoolers, which they link to greater inhibitory control resources.

Developmental research on executive function in India is limited, but extant work has found some advantages within Indian populations, though they are confounded with bilingualism (e.g., Bialystok, 2010; Bialystok & Viswanathan, 2009). If broader cultural differences play a role in these findings, this might indicate that children from India, like their East Asian neighbors, develop some executive function abilities earlier in life than their Western peers. Consequently, we might expect to see cross-cultural differences in relational reasoning as a result of differences in the development of executive function.

Visual attention Cross-cultural studies on visual attention suggest that people from East Asian cultures preferentially attend to relational patterns while people from Western countries attend more to individual objects (Kuwabara & Smith, 2016; Duffy et al., 2009; Kitayama et al., 2003; Masuda & Nisbett, 2001; Ji, Peng, & Nisbett, 2000). This East Asian tendency to integrate visual context may facilitate pattern detection in relational reasoning tasks.

Other work has found parallel evidence for contextual attention in India and China, relative to the US (Mendel et al., 2009; Chua, Boland, & Nisbett, 2005). These studies find that Americans often attend more to focal objects and less to relations than East Asians. Meanwhile, people from East Asian and Indian cultures attend relatively more to peripheral and background visual contexts, which could facilitate relational reasoning.

Social cognition and processing styles Tendencies toward holistic or analytic processing also vary across cultures (Choi, Nisbett, & Norenzayan, 1999), and variation in these processing styles has, in turn, been implicated in relational reasoning and analogical problem solving (e.g. Riding & Cheema, 1992; Duffy et al., 2009). Childhood socialization with a strong focus on interpersonal relationships might selectively guide children's attention to relations even outside the social realm, and indirectly promote relational reasoning. Witkin et al. (1974) argue for this socialization route in establishing culture-specific processing styles.

In India, evidence on processing styles suggests a mixture somewhere between US analytic and Chinese holistic tendencies (Monga & John, 2007; Asthana, 1956). These findings suggest that India may be intermediate between the US and China with respect to processing style.

Conclusion

This study finds strong evidence for differences in preschoolers' relational reasoning in India and China, and modest evidence for differences between India and the United States. Future work is needed to address several open questions about the time course of these differences over early development, and their generality across different measures. However, these initial findings suggest that Indian children's relational reasoning may be intermediate between their peers in China and the US at this age, lending further support to the view that differences in learning environments shape variation in the emergence of relational reasoning, a core component of abstract thought. Because relational reasoning is critical for early education, and STEM learning in particular, this work may have broad implications, with the potential to inform educational practices, and to do so in a culturally-informed and a context-specific fashion. More immediately, this work provides a foundation for future research designed to tease apart accounts of contextual influences on relational reasoning that are confounded in mainstream American and Chinese cultures, but may not be in Indian cultural contexts.

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