Relational abstraction in early childhood: Three cultures and three trajectories

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Abstract

Abstract reasoning in early childhood is often described as following a "relational shift," over which children become increasingly sensitive to relations. However, recent work has challenged the generality of this account, showing that children in the US and China follow distinct trajectories in a relational match-to-sample task (Carstensen et al., 2019). This difference aligns with multiple cultural and linguistic factors implicated in relational reasoning, in which English speakers in the US and Mandarin speakers in China appear at opposite ends of a continuum spanning from a focus on objects (US) to relations (CN). We explore early relational reasoning in a context that represents a cultural middle ground with a key linguistic similarity (noun spurts) to the US: Korean-learning children in South Korea. In two experiments with 262 Korean children, we document relational reasoning in this novel cultural context, revealing similarities and differences to developmental trajectories in the US and China.

Keywords: cognitive development; causal learning; relational reasoning; language; culture; context; South Korea

Introduction

How do people come to reason abstractly, conceiving of objects not just in terms of properties, like color and shape, but in terms of more general similarity, like being *the same* in color or shape? Abstract reasoning in early childhood is often described as following a "relational shift," over which children become less focused on object properties and surface features, and increasingly sensitive to relations (e.g., Gentner, 1988; Gentner & Rattermann, 1991; Gentner, Rattermann, Markman, & Kotovsky, 1995). However, recent work has challenged the generality of this account, showing that children in the US and mainland China follow two distinct trajectories in a causal relational match-to-sample (cRMTS) task between 18 and 48 months (Carstensen et al., 2019).

In this task, children see four pairs of blocks placed on a toy, which plays music only for two of the four pairs. These causal pairs either match in color and shape (*same* condition) or are mismatched (*different* condition). Children then choose between a novel *same* or *different* pair to activate the machine. In order to succeed, they must generalize from the pairs that worked during the training trials (e.g. green cubes and red pyramids) to a pair that is composed of novel shapes and colors, but which is relationally consistent with their training (e.g., yellow spheres).

This is a challenging task, and intriguingly, performance in the US follows a U-shaped learning trajectory, with strong performance in relational matching between 18 and 30 months, poor performance between 36 and 48 months, and later recovery. In contrast, children in China demonstrate strong performance at the youngest end of this age range and no evidence of decline, showing comparable or improved performance by the preschool age. Carstensen et al. (2019) interpret these findings in terms of the rational learner account, originally proposed by Walker et al. (2016). On this view, children have genuine relational concepts from a very young age, but acquire learned biases to privilege or neglect relational information. But what features of children's environments shape these biases?

The two distinct trajectories—U-shaped in the US and linear in China—coincide with multiple linguistic and cultural factors that have been implicated in relational reasoning and that differ between these countries. These factors include differences in language (Hoyos, Shao, & Gentner, 2016; Carstensen et al., 2019), visual attention (Kuwabara & Smith, 2012; 2016; Christie, Gao, & Ma, 2020), social reasoning (Duffy et al., 2009), and executive function (Richland et al., 2010), among others. While there are a range of explanations that draw on these factors, many of these accounts argue that these cross-cultural differences promote (or decrement) relational reasoning by inducing a bias toward (or away from) relational and contextual information. On this view, English speakers in the US and Mandarin speakers in China appear at opposite ends of a continuum, from a focus on objects in the US to one on relations in China. Here, we measure early relational reasoning in a context that represents a cultural middle ground between the US and China, with a key linguistic similarity (early noun bias in word learning) to the US: Korean-learning children in South Korea.

The current work aims to inform ongoing discussions of the role that language plays in the trajectory of early relational reasoning. For example, Hoyos, Shao, and Gentner (2016) proposed that the overrepresentation of nouns in (English) language learning creates a temporary bias toward objects and object properties, like shape, causing the observed decline in relational matching between toddlers and preschool-aged children in the US. Mandarin Chinese learners, unlike English-learning children, do not show a strong noun bias in their early lexicons (Tardif, Shatz, & Naigles, 1997; Frank et al., 2021), and also do not show the decline in relational matching that Hoyos et al. attribute to avid noun learning. While there is mixed evidence on lexical

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bias in the early vocabularies of Korean speakers, one of the largest studies to date, with over 1,300 Korean-speaking children, finds an early noun bias among Korean leaners that is comparable to that in English (Frank et al., 2021; see also Au et al., 1994; Kim et al., 2000; cf. Choi & Gopnik, 1995[1]).

Outside of language, many of the accounts linking relational reasoning to learning contexts make similar predictions about differences between East Asian cultures and those in North America and Europe. For example, Choi et al. (1999) review cross-cultural differences in attention to social context and argue for a broad divide between East Asian and Western cultures. Choi and Nisbett (1998) find that when situational information is made salient, Korean adults are more likely than Americans to incorporate this context in their causal reasoning. Korean adults also tend to make more situational attributions than American adults (Choi et al., 2003). Additionally, Korean preschoolers have been shown to privilege traditional social factors (age) over performance in selecting social partners (Beom & Choi, 2020). Other work suggests a similar cultural divide in visual attention and aesthetics, with adults from East Asian cultures allocating greater attention to background information in visual scenes and preferring richer visual contexts (Masuda et al., 2008; Boduroglu et al., 2009; Masuda & Nisbett, 2001). These differences in visual attention have been observed to emerge early in development (in Japanese children), and have been proposed to influence relational reasoning (Kuwabara & Smith, 2012; 2016; Imada et al., 2013). Finally, research on executive function has shown advantages for Korean and Chinese preschoolers compared to Western populations (Oh & Lewis, 2008; Richland et al., 2010), which Richland and colleagues have linked to differences in relational reasoning.

However, despite some general similarities between East Asian cultures and specific commonalities between South Korea and China in particular, there is reason for caution when generalizing across these contexts. More fine-grained analyses highlight important differences between South Korea and China (Zhang et al., 2005), and increasing similarities between Korea and Western cultures, as a result of globalization (Shin & Choi, 2008) and rising demand for English-language education from an early age (Lim, 2021).

Taken together, this prior work suggests that Korean word learning shows a similar noun bias to that in English, but provides a cultural middle ground between the US and China. If lexical bias alone drives the trajectory of relational matching, then learners in Korea should show performance resembling their peers in the US. But if one or more cultural or cognitive factors (e.g., visual attention, social reasoning, or executive function), or a combination of lexical bias and non-linguistic factors are responsible for the unique trajectories in the US and China, then we would expect to find that the development of relational reasoning in Korea more closely resembles that in China, or follows a unique path altogether.

The present study

Our study has several related goals. First, we seek to document children's relational performance and accompanying relational bias in a novel cultural context, South Korea, that shares some features of interest with the US and some with China. This will inform ongoing work investigating which cultural and linguistic factors are causally relevant for determining naturally occurring cross-cultural variation in the emergence of relational reasoning.

Second, our approach presents an opportunity to evaluate two key predictions of the *rational learner account,* first proposed by Walker et al. (2016), and later developed by Carstensen et al. (2019). These are (1) *early consistency* in the emergence of relational reasoning across learning contexts, and (2) *later variation* in the developmental trajectory over early childhood (to the extent that relevant features of the learning context vary).

In the following experiments, we begin by measuring the performance of Korean toddlers between 18 and 30 months, the youngest group demonstrated to succeed in the relational reasoning paradigm (cRMTS). In Experiment 1, we ask whether the success observed in the US and China at this age extends to our South Korean sample, a test of *early consistency*. Next, we turn to the possibility of *later variation*. We first evaluate variation in children's expectations about the likelihood of relational causes (Experiment 2a), and then in their performance on relational matching (2b). To preview our results, these data bear out our predictions on consistency and variation, but with novel and important caveats that we address in the discussion.

Experiment 1: Consistency in early emergence

In previous work, Walker and colleagues demonstrated that toddlers (18-30 months) in the US can solve a causal Relational Match-to-Sample task (cRMTS), but subsequently decline to chance performance by 3-4 years old (Walker & Gopnik, 2014; Walker et al., 2016). Given this early success, Walker and colleagues argue that children's ability to infer object-based and relational concepts likely develops roughly in tandem, with the later decline reflecting a failure to apply relational reasoning, rather than a lack of ability.

Carstensen et al. (2019) extend this work, finding that the early success observed among toddlers in the US is also shown by their counterparts in China. The experiments in the current study follow the same design as Carstensen et al. (2019) and compare novel data with children in Korea to previous findings with participants in the US and China. Here, we begin by evaluating the evidence for early emergence of relational reasoning in the cRMTS paradigm with toddlers in Korea, a test with the potential to falsify the rational learner prediction of *early consistency*, that younger children with weak or no relevant biases will tend to perform well in relational reasoning.

[1] While Choi and Gopnik (1995) found comparable numbers of nouns and verbs in Korean infants' vocabularies, Au et al. (1994) and Kim et al. (2000) document an overrepresentation of nouns in highly similar studies, consistent with the findings in Frank et al. (2021). Despite an overall noun bias, Kim et al. (2000) do show an advantage for verb learning in Korean infants relative to US infants.

Participants

A total of 91 Korean-speaking 18-30-month-olds (M = 24.0 months; 48 female) from Korea took part in Experiment 1, with 41 in the *same* condition and 50 in the *different* condition. An additional 17 toddlers were tested, but excluded as a result of failure to complete the task (16), or because of a technical issue with the stimuli (1). Children were recruited and tested at preschools and public parks, and through a lab database, with testing conducted either in the lab or at participants' homes in and around Seoul, South Korea. Participants were pseudo-randomly assigned to each condition, and we applied Bayesian optional stopping to determine our sample size, stopping data collection when we reached a Bayes factor of 3 in favor of the test (different from chance) or null (chance performance) hypothesis in a binomial comparison. If we did not satisfy this criterion, we stopped data collection at 50 participants per condition, a sample slightly larger than that in Carstensen et al. (2019).

Procedure

The materials and procedure were matched to Walker et al. (2016, Experiment 1) and Carstensen et al. (2019, Experiments 1-2), with the exception that the instructions were presented in Korean. The original English instructions (described here in English) were independently translated and back translated by Korean-English bilinguals, with back translation checking and adjustments to ensure accuracy.

Children were tested in individual sessions, seated at a table across from the experimenter. After a brief warm up, the experimenter started the cRMTS task. The experimenter placed pairs of painted wooden blocks on top of a cardboard box, which appeared to play music in response to some pairs and not others. In reality, the experimenter triggered the music by covertly pressing a button to activate a wireless doorbell inside the box. The block pairs exemplified the *same* relation (matching in shape and color), which activated the box in the same condition, or the *different* relation (mismatched in shape and color), which played music in the different condition (see Figure 1).

The experimenter began by placing the box on the table, 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 introduced a pair of blocks, said "Let's try!" and put both blocks on top of the toy simultaneously. The toy played music and the experimenter said "Music!" Then she picked up the blocks and placed them back on the toy, which again played music, saying "These ones made my toy play music!"

On the second training trial, the experimenter repeated this procedure with a new pair of blocks in the opposite relation (*same* or *different*). The new pair did not make the toy play music, and the experimenter responded to the first try with "No music!" and after the second try, said "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.

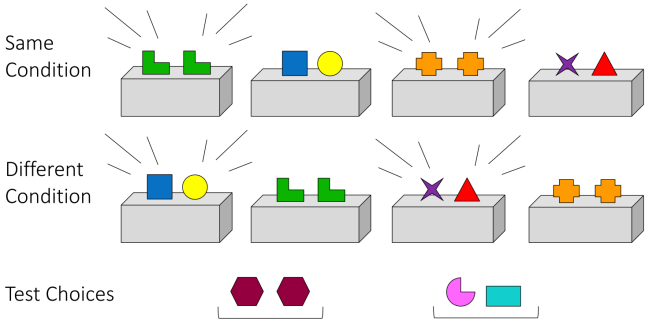

Figure 1: Schematic of the causal Relational Match-to-Sample training (top two rows) and test trial (bottom), reproduced from Carstensen et al. (2019).

After the four training trials, the experimenter said "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 presented the child with two new test pairs of novel blocks, one *same* pair and one *different* pair on either side of the toy. Each pair was displayed on a tray, which the experimenter held up as she 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 trays were placed 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 their training.

Results and discussion

All data and analysis scripts for these experiments are available at https://osf.io/ue6r3.

We used the Bayesian binomial test from our stopping rule to analyze data in each condition. We find that toddlers in Korea are similar to their counterparts in China, showing early success in relational matching in the *same* condition (n=41, M=67%, Bayes Factor$_3$=4.07), but not in the *different* condition (n=50, M=50%, BF$_3$=.33).

In all three countries, there is evidence that children can successfully engage in relational reasoning at an early age, selecting the relationally correct solution in the *same* condition. This offers support for the cross-cultural generality of early success in this paradigm, is consistent with the view that toddlers have genuine *same* concepts, and aligns with the *early consistency* prediction of the rational learner account.

At the same time, we observe near-chance responding in the *different* condition, with our Korea sample echoing the previous results from children in China (for condition

differences in the CN sample, see Figure 6 here and Supporting Information for Carstensen et al., 2019). Note, however, that we have not met our threshold for supporting the null hypothesis, so additional data is needed to conclude whether this qualitative similarity is truly significant. Taken at face value, this finding may suggest cultural specificity: perhaps shared features of learning environments in China and Korea advantage reasoners in the *same* condition relative to the *different* condition.

This finding could also reflect a cross-cultural consistency—specifically, that reasoning about *same* is earlier-emerging than reasoning about *different* relations in general. Indeed, this *same*-advantage is consistent with findings in studies of US infants (Hochmann et al., 2016; Hochmann et al., 2018). Similar findings exist with older US children between 30 and 36 months (Walker et al., 2016), during the initial downward trajectory of the U-shaped curve. Below-ceiling performance in this task is associated with an advantage for the *same* relation across the US, China, and now Korea. This repeated asymmetry suggests that there may be a cross-cultural advantage for reasoning about *same*.

Experiment 2a: Variation in relational bias

In Experiment 1, we evaluated one prediction of the rational learner perspective, that the emergence of relational reasoning among young children, who are subject to less bias from previous experience, will show consistencies across varied contexts. The second prediction of this account, *later variation*, is that older children will diverge in their performance to the extent that their environments differ, as a result of context-specific experience influencing the development of their biases.

Carstensen et al. (2019) used an ambiguous version of the cRMTS task in Experiment 1 to measure children's bias toward relational versus object-based solutions. They found that differences in relational bias between 3-year-olds in the US and China predicted relational reasoning performance in each of these groups. Here, we use the same ambiguous cRMTS task to measure bias in Korea. This measurement of relational bias provides a test of *later variation* in relational reasoning, and will also inform questions of which factors that vary across cultures are critical for observed differences in performance between the US and China.

Participants

A total of 55 Korean-speaking 36-48-month-olds (M = 41.2 months; 22 female) in Korea took part in Experiment 2a. This sample size was selected to match that of the US sample in Carstensen et al. (2019, Experiment 3). One additional child participated, but was excluded for failing to follow instructions. Recruitment and testing locations were the same as in Experiment 1.

Procedure

Materials were identical to those in Experiment 1. The procedure closely resembled that of the "different" condition, but with three modifications to create an ambiguous casual structure (see Figure 2). First, in the training trials, one of the blocks (represented by the *blue square* in Figure 2) repeatedly appears in *both* different pairs that play music. This recurring block provides support for an object-based hypothesis (i.e., the blue square is causal). Second, the test trial was composed of the blocks that were previously observed in the *different* training pairs, regrouped to create the *same* (object match) and *different* (relation match) pairs. Finally, the experiment included only the *different* condition and not *same* due to constraints of the study design (i.e., object and relational matches based on a *same* pair of objects will be identical).

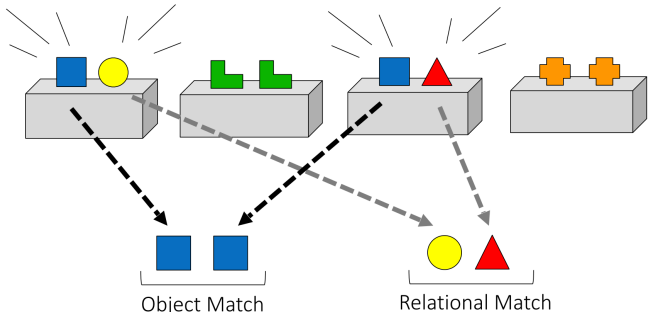

Figure 2: Schematic of the Ambiguous cRMTS training (top row) and test trial (bottom), which pits an object match solution against a relational match. Reproduced from Carstensen et al. (2019).

As in Experiment 1, the experimenter asked the child to choose the pair that would make the toy play music. The child's first point or reach was scored as consistent with either an object selection or a relational selection.

Results and discussion

As in Experiment 1, we used the Bayesian binomial test from our stopping rule to analyze data in the ambiguous cRMTS task. The Korean 3-year-olds in our sample show intermediate scores in the bias assessment (n=55, M=53% relational, BF_3=.34), with no clear preference for the object bias observed in the US or the relational bias observed in China (see Figure 3).

This result bears out the rational learner prediction of *later variation* in the development of relational reasoning, establishing a qualitatively different finding—no bias—among preschoolers in Korea. This difference in baseline bias between children in all three countries additionally implies that the factor or factors that are causally relevant for differences in bias between the US and China additionally distinguishes the learning context in South Korea from each of these countries.

Finally, this finding presents a unique natural condition, providing the opportunity to measure relational reasoning performance in a *neutral* population of young children with no measurable bias toward object-based or relational solutions, the goal that we take up in Experiment 2b.

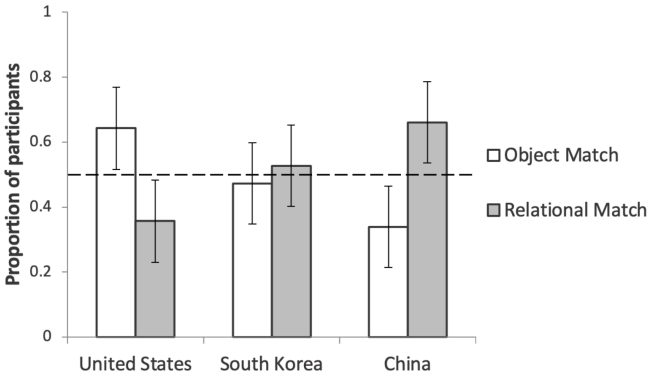

Figure 3: Proportion of object and relational matches selected by South Korean children in the ambiguous matching task (Experiment 2a), compared to children from the US and China in Carstensen et al. (2019). Error bars indicate 95% CIs and the dotted line, chance performance.

Experiment 2b: Variation in relational reasoning

In Experiment 2a, we found that 3-year-olds in Korea show no bias toward relational or object-based solutions in an ambiguous context. Critically, this is the age at which we observe the largest differences in relational reasoning *performance* among children in the US and China, with the former performing at chance and the latter significantly above it. This differential performance is accompanied by opposite *biases* toward object-based and relational solutions, that seem likely to moderate performance in relational reasoning. How will Korean 3-year-olds perform in our relational matching task without a clear bias in either direction to influence their responding?

If they perform above chance, this could suggest that success at this age is the more general pattern, in that it does not depend on a relational bias. Conversely, if Korean 3-year-olds perform at chance, it may indicate that chance performance is the more general developmental pattern, and that a relational bias like the one observed in China is necessary for robust relational reasoning at this age.

In this experiment, we also extend our measurement of spontaneous trajectories for relational reasoning in the US and Korea by measuring cRMTS performance among 4-year-olds in both countries. To our knowledge, this is the first study to document performance in this paradigm with children over 48 months, testing for the hypothesized second half of the U-shaped curve within the US population.

Participants

A total of 100 Korean children aged 36-48 months (M = 41.5 months; 49 female; 50 per condition), 16 Korean children aged 48-60 months (M = 53.7 months; 7 female; 8 per condition), and 49 US children aged 48-60 months (M = 53.2 months; 23 female; 10 in the *different* condition and 39 in the *same* condition) participated in Experiment 2b. Participants were pseudo-randomly assigned to the *same* or *different* condition, and we followed the same Bayesian optional stopping protocol as in Experiment 1 for determining the sample size, stopping at a maximum of 50 participants per condition when we did not satisfy our stopping criterion.[2] Recruitment and testing locations within Korea were the same as in the two previous studies. In the US, all participants were recruited and tested at a museum in San Diego.

Procedure

The materials and procedure were identical to those in Experiment 1, with the exception that US children were tested in English.

Results and discussion

As in the previous studies, we used the Bayesian binomial test from our stopping rule for our analysis. Our data suggest that at 3 years old, performance in the Korean sample does not differ from chance (*same* n=50, M=59%, BF_3=.58; *different* n=50, M=53%, BF_3=.81), meaning that it is intermediate to that in the US and China. Meanwhile, at 4 years old, children in both Korea and the US perform above chance (KR: *same* n=8, M=100%, BF_3=9.18, *diff* n=8, M=100%, BF_3=9.18; US: *same* n=39, M=77% , BF_3= 60.97, *diff* n=10, M=90%, BF_3= 5.48).

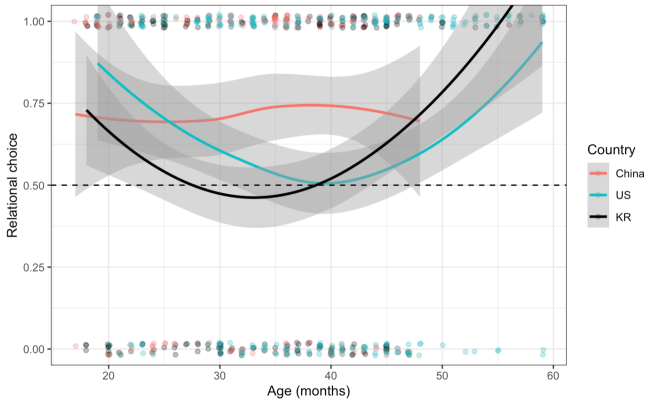

Figure 4: Overall relational matching trajectories, compared to Carstensen et al. (2019), plotted with Loess smoothed fit lines. Shaded regions indicate 95% CIs.

We also compared our full cross-sectional data in this paradigm (Experiments 1 and 2b) with comparable data from children in China and the US from Carstensen et al. (2019); see Figure 4. For this, we fit a Bayesian logistic regression predicting per-trial cRMTS performance as a function of age (in months, centered), quadratic age (to account for U-shaped

[2] We over-recruited US 4-year-olds in the *same* condition due to a miscommunication of the stopping rule. If we had followed our rule as intended, we would have stopped at a sample size of 23 with the same qualitative outcome (M=78%, BF_3= 9.59).

trajectories[3]), condition (same or different), country (Korea, US, or China), and their interactions.

This model did not converge, so we fit the same model using a standard logistic regression. There was a main effect of the quadratic age term (β=-0.09, 95% CI [-0.20, -0.02], p=0.03), and significant 2-way interactions between quadratic age and condition (β=0.12 [0.02, 0.25], p=0.03), and quadratic age and country for China compared to the US (β=0.21 [0.06, 0.40], p = 0.01). There were significant 3-way interactions between age, condition, and country for both China (β=-0.97 [-1.87, -0.28], p=0.01) and Korea (β=-0.66 [-1.18, -0.18], p=0.009), compared to the US. Finally, there were also significant 3-way interactions between quadratic age, condition, and country for both China (β=-0.27 [-0.48, -0.10], p=0.005) and Korea (β=-0.17 [-0.33, -0.03], p=0.02), compared to the US (see Figure 5).

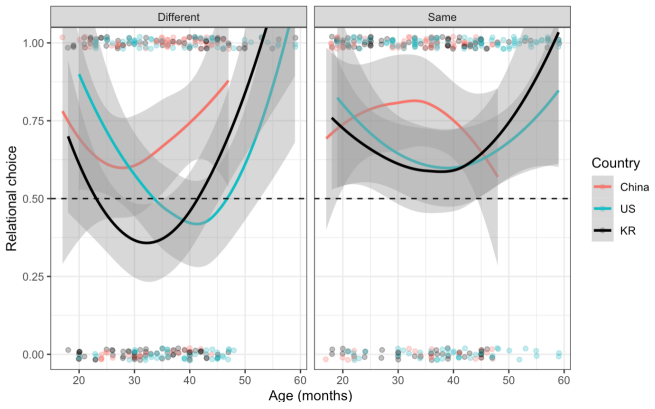

Figure 5: Relational matching in Experiments 1 and 2b, by age, condition, and country, compared to Carstensen et al. (2019). Plotting conventions are the same as in Figure 4.

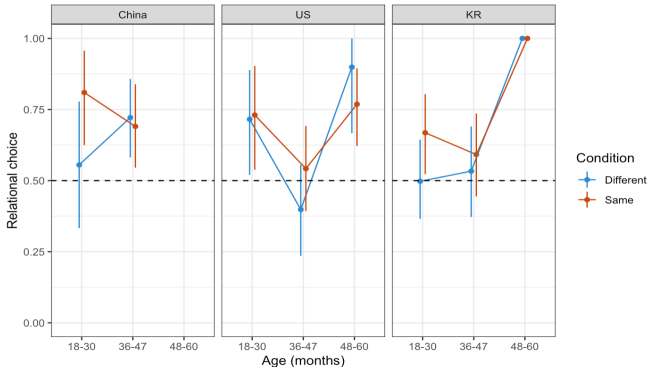

Figure 6: Mean performance in each country plotted according to the age and condition bins in our main analysis.

Our binomial analysis does not support the null or test hypotheses for 3-year-olds in Korea, though we find clear evidence that 4-year-olds in Korea and the US succeed in choosing the relationally correct solution in both *same* and *different* conditions. Figure 4 shows overall performance at all ages for children in our Korean sample, alongside comparable data from their peers in the US and China, combined across conditions. This is the first empirical documentation of the full trajectory of the U-shaped curve in the US, which had been previously hypothesized on the basis of adult performance in this task and success in related reasoning tasks by preschool and school-aged children. Within and across conditions, the developmental trajectory observed in our Korean sample qualitatively resembles that in the US. And indeed, the overall performance in both countries is better characterized by models that incorporate a quadratic age term in addition to a linear one, enabling U-shaped model fits of the type shown in Figures 4 and 5.

General discussion

We document the early trajectory of relational reasoning among children in Korea between 18 and 60 months of age, using two relational matching tasks. In doing so, we find support for two key predictions of the rational learner account: *early consistency*, which is partially supported by toddlers' above chance performance in the same condition, and *later variation*, evidenced in our measure of relational bias.[4] We also measure the relational matching performance of 4-year-olds in the US and Korea, who show robust success, providing evidence for the upswing in a hypothesized U-shaped learning trajectory characterizing US performance.

Although additional work is needed, the current results provide evidence for a unique trajectory in Korea, and most strikingly, one in which older children's performance is not influenced by a baseline bias toward object-based or relational solutions. This finding has implications for determining which factors likely lead to differences in the development of relational reasoning. If, following Frank et al. (2021), we take early lexical biases to be comparable in the US and Korea, then some additional causal factor must shape the difference in relational bias between children in the US and Korea.

Across these two experiments, we find additional support for the generality of the rational learner account, that differential biases toward objects or relations predict older children's performance in relational matching, and further elaborate specific accounts of the developmental trajectories in the US and Korea. In line with previous findings, we document a link between culturally variable preferences and variation in relational matching. At the same time, the current findings underscore variation in early abstract reasoning: our findings suggest that there is neither a single common trajectory nor two typical trajectories in early relational responding, and that both linguistic and cultural factors may contribute to shaping early abilities.

[3] We also fit a version of this model without the quadratic age term, but the model with quadratic age outperformed the simpler alternative in model comparison ($\chi^2(6)=13.22$, p=.03).

[4] The lack of biased responding among 3-year-olds in Korea may be due to chance performance rather than a true lack of bias; but note that both possibilities represent cross-context diversity at this age.

Acknowledgments

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