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Author
Baer, Carolyn

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Perceptual and Memory Metacognition in Children

Carolyn Baer (carolynbaer@berkeley.edu)
Department of Psychology, University of California, Berkeley, CA, USA.

Simona Ghetti (sghetti@davis.edu)
Department of Psychology, University of California, Davis, CA, USA.

Darko Odic (darko.odic@psych.ubc.ca)
Department of Psychology, University of British Columbia, Vancouver, BC, Canada.

Abstract

Confidence can be experienced for all kinds of decisions – evaluating the value of a piece of artwork, determining whether the lights are flickering, or remembering where we left our keys. These are fundamentally different kinds of decisions, but does that mean the confidence we feel is also fundamentally different for each one? Here, we test competing theories of domain-generality and domain-specificity in metacognitive ability by correlating individual differences in memory and perceptual confidence judgments in childhood. Children performed a recognition memory task and an area discrimination task followed by confidence judgments. Using 4 measures of metacognitive ability (indicated by higher confidence for accurate compared to inaccurate judgments: difference scores, meta-d', MRatio, and HMeta-d'), we find no significant correlations between this ability in memory and perceptual tasks. These findings support an account of domain-specificity in children's metacognitive abilities.

Keywords: metacognition, confidence, certainty, memory, perception, development, domain-general

Introduction

A hallmark of the human experience is a sense of confidence in our decisions. Feelings of wariness tell us when to be skeptical of others or to check the lock on the door again, and feelings of certainty push us to act in anticipation of positive outcomes. For all kinds of decisions, from memories to math problems to social etiquette, we can evaluate the subjective strength of our decisions using metacognitive processes. Notice though, even in this description, there is an assumption that feelings of confidence are fundamentally the same across all these decisions: we experience the same unitary feeling and it serves the same function (i.e., domain-generality, akin to *g*). This assumption has led theorists to propose that feelings of certainty are a key signature of (and possibly the mechanism for) conscious thought because of their ubiquity and the possibility of their shared representational code across all decisions (Shea & Frith, 2019). Is this assumption of domain-generality warranted given that decisions in different cognitive domains are based on vastly different cognitive operations?

One piece of evidence for domain-generality is commonality in the *unit* of confidence representation. Some theories of confidence propose representational structures that should act similarly across all decisions, using the same units regardless of the content domain of the processing systems. For example, confidence may be generally construed as reflecting the subjective probability of being correct (Pouget et al., 2016). In this way, confidence is the result of a statistical computation much like a t test: it can take many different inputs (e.g., math scores, social bias averages) and transform them into a single, useful output (e.g., a standardized effect size or *p* value). As another example, confidence could reflect an error signal (or lack thereof, Boldt & Yeung, 2015). Like a probability judgment, an error signal could take place following any kind of decision, and it tracks the same information as confidence judgments (see Fandakova et al., 2017). Both probabilistic and error monitoring accounts are also consistent with emerging developmental evidence showing early metacognitive reasoning in infants and preschool children (Goupil et al., 2016; Lyons & Ghetti, 2011), as probabilistic reasoning and error detection are both known to occur in infancy (e.g., Denison & Xu, 2019).

Consistent with a domain-general unit, experimental evidence in both adults and school-aged children suggests that confidence representations can be compared and have carry-over effects even between unrelated tasks. In one paradigm, participants were asked to evaluate which of two decisions they were most certain of getting correct. When the two decisions come from distinct cognitive acts, such as judgments of number and emotion or vision and audition, both adults and children as young as 6 years made these comparisons as effectively as they did for two decisions from the same cognitive domain (Baer & Odic, 2020; De Gardelle et al., 2016), suggesting a common unit of comparison for perceptual confidence among some cognitive domains. Similarly, when participants were asked to provide retrospective confidence judgments after each individual cognitive decision, their confidence from previous decisions 'leaked' into subsequent judgments (Rahnev et al., 2015). Notably, leaking also occurs when a memory decision is followed by a perceptual decision or vice versa (Kantner et al., 2019), suggesting related confidence units for these two diverse decision types.

A second piece of evidence for domain-generality are correlations in the ability to reason about confidence in different cognitive domains (e.g., memory and perception). If confidence is computed through a domain-general mechanism, then metacognitive abilities should correlate across otherwise independent cognitive domains.

Accordingly, some studies find that confidence *sensitivity* (the precision with which one can distinguish states of confidence) is correlated between distinct tasks (see Rouault et al., 2018 for a review). For example, confidence sensitivity in semantic memory, executive functioning, and visual perception correlates in adults (Mazancieux et al., 2020), as does number, area, and emotion perception in children (Baer et al., 2018).

However, other empirical work fails to find correlations between confidence reasoning abilities across domains, particularly in childhood. Confidence sensitivity in emotion and numerical perception was uncorrelated in children aged 5-8 (Vo et al., 2014, though see Baer et al., 2018), as were confidence reports in mathematical and memory strategies from age 8 to age 10 (Geurten et al., 2018) and math and spelling confidence sensitivity in 7-8-year-olds (Bellon et al., 2020). There are also patterns of distinct neural activation for metacognitive judgments from different domains in adults (see Rouault et al., 2018).

One possible explanation for these patterns is theoretical. Perhaps confidence is computed by domain-specific metacognitive abilities (e.g., by memory-specific metacognition or number-specific metacognition), which change over time to either become or act domain-general. This would account for the lack of correlations in studies with children, while still accounting for the evidence that confidence representations are comparable and influential across domains for adults. To test this account, we need to examine in children those correlations between metacognitive abilities documented in adults, and we need to use the same methods of quantifying metacognitive abilities to facilitate comparison (e.g., meta-d' and MRatio, as used by Mazancieux et al., 2020). If metacognitive abilities are domain-specific in children, then we would expect these measures to be uncorrelated in children, despite being corrected in adults.

A second possible explanation is that confidence representations reflect a domain-general process, with conflicting results caused by the challenges of obtaining sound metacognitive judgments uncontaminated by their first-order task performance (e.g., separating perceptual confidence from perceptual ability; see Paulewicz et al., 2020), or other methodological challenges like underpowered samples (see Mazancieux et al., 2020). This is particularly relevant for the study of confidence in childhood, where there is often dramatic improvement across age groups as children's cognitive abilities develop. To test this, we need to use the best currently available measure for separating metacognitive judgments from first-order task performance (MRatio, Fleming & Lau, 2014), and use a sample large enough to detect the expected correlations. With these changes, this account predicts that there should be cross-domain correlations in confidence sensitivity, even in younger children.

Methods

We administered children between the ages of 4-7 an episodic memory and a perceptual confidence task. This age group overlaps with Baer & Odic's study (2020) showing domain-general units of perceptual confidence, but investigates younger children to detect possible developmental differences between children who have or have not entered structured schooling at age 5-6. By using Episodic memory and perception were specifically chosen as first-order tasks from the domains tested by , we also mirror the studies conducted with adults (e.g., Mazancieux et al., 2020 as they are well-studied and easy to administer with children) that have provided evidence both in favor and against domain-generality, allowing for comparison to other age groups.

Participants

We recruited 168 children ages 4 through 7 years from local schools and daycares (*M* = 6;4 years;months, range = 4;06 – 7;11, 86 girls). Following our preregistered plan (https://osf.io/yq73r/), we excluded all data for any child who failed to complete the study (*n* = 4), who did not understand the memory or area task (quantified as accuracy below 55%, 33 for memory, 24 for area), or who had no variability in their confidence judgments (3 for memory, 6 for area). With these exclusions, we had a sample of 110 children with both metacognitive measures to assess correlations (*M* = 6;5, range = 4;5 - 7;11, 64 girls). Two additional children were tested but not included in any analyses because their parents indicated that they heard English less than 50% of the time. Children generally came from middle-class White and East/Southeast Asian backgrounds, as is representative of the large North American city where testing took place. All children were tested individually in a quiet area of their school.

Materials and Procedures

Children completed two tasks on a laptop in a counterbalanced order: a memory task and a perceptual task, each with a metacognitive judgment following each answer. The memory and perceptual tasks were designed to be equated at 70% accuracy at the group level to facilitate comparisons between them.

Memory Task We presented children with kid-friendly drawings (Rossion & Poutois, 2004) that were recolored to be either yellow or blue (see Fig. 1), and asked children to recognize the association between item and color by selecting which of the two versions of the object, yellow or blue, they had seen. In the Encoding phase, children saw a series of 49 pictures for 2000 *msec* (if age 4 or 5) or 1500 *msec* (if age 6 or 7). To ensure that children attended to both the identity of the picture and its color, children were asked to respond to each item by identifying it and stating its color (e.g., a blue fox). The first three items were the same for all children so they could be used as training items for the metacognitive

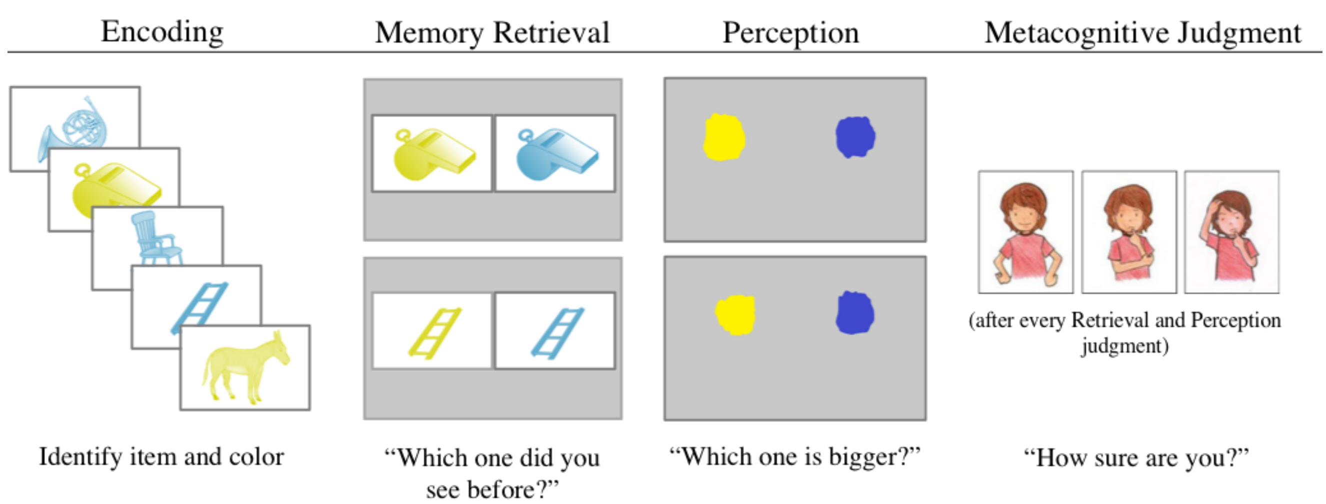

Figure 1: Stimuli used in the study. In the Encoding phase, children identified the item and its color one at a time. In the Retrieval phase, children identified which color of that item they saw during Encoding. In the Perception task, children indicated which shape was bigger. Following every Memory and Perceptual judgment, children gave a confidence judgment on a three-point scale. Memory and Perception sections were counterbalanced across children.

measure; all other items were presented in a randomized order. Thirty-two of the items were used as target items in the Retrieval phase and were counterbalanced to appear yellow for half of participants and blue for the other half, with every child seeing equal numbers of yellow and blue items. The remaining 14 items were distractors to make the task more challenging.

The Retrieval phase immediately followed Encoding, separated only by the confidence scale training (described below). Children were shown the target items one at a time and asked to identify whether they saw the yellow or blue version (see Fig. 1). No feedback was given about accuracy. The 32 trials were presented in a random order, and were supplemented with 4 'Impossible' trials with items they had never seen before to examine children's use of the confidence scale.

Perception Task Children completed an area discrimination task in which they indicated which of two amorphous shapes was bigger (see Fig. 1). Shapes always appeared on separate sides of the screen, and were slightly jittered to prevent children from comparing their heights directly to determine the larger area. The trial disappeared after 2000 msec (for 4-5-year-olds) or 1500 msec (for 6-7-year-olds). To achieve 70% accuracy with some variability (to match the Memory task), we presented children with 4 similar ratios of pixels that should lead to 65-75% accuracy in these age groups (Odic, 2018). For 4-5-year-olds, these ratios were 1.2 (e.g., 22500 vs 18750 pixels), 1.17, 1.14, and 1.1. For 6-7-year-olds, they were 1.1, 1.08, 1.05, and 1.03.

As with the Memory task, there were 32 target trials supplemented by 4 'Impossible' trials (where the two shapes had the same number of pixels), which all appeared in a random order. No feedback was given about children's accuracy.

Metacognitive Judgments Following each trial of both the Memory and Perceptual task, children made a metacognitive assessment of their confidence using a standard 3-point scale for children (Hembacher & Ghetti, 2014). Each level of confidence was represented in the scale by an image of a gender-neutral child demonstrating a facial and body expression associated with high, moderate, and low confidence (see Fig. 1).

Prior to the test trials in both the Memory and Perceptual tasks, children completed 5 training trials to ensure they understood how to use the scale. The experimenter told children to use the "really sure" face when they definitely knew the answer or didn't have to think at all, to use the "kind-of sure" face when they maybe knew the answer or had to think about it a little bit, and the "not so sure" face when they didn't know the answer or had to think really hard about it. Children then went through the practice trials with corrective feedback from the experimenter based on the child's displayed confidence when answering the question (e.g., "It seemed like you were really sure about that one, so you should have picked the really sure face"). To help elicit feelings of confidence from the entire scale range, three practice trials were easy (relying on primacy effects for memory, and using a ratio of 1.5 for perception), and two were impossible.

Results

Our analysis plan was preregistered on the OSF (https://osf.io/yq73r); any exploratory analyses are noted as such below.

Memory and Perceptual Accuracy

We first sought to confirm that children understood both the Memory and Perceptual tasks. Children correctly identified the color of the images they encoded on 69.18% of trials (*SD*

= 8.89%), $t(109) = 22.61$, $p < .001$, $d = 2.16$, and correctly identified 71.25% ($SD = 9.26$) of bigger shapes, $t(109) = 24.06$, $p < .001$, $d = 2.29$. An exploratory paired t test found that Perceptual accuracy was marginally higher than Memory accuracy, $t(109) = -1.74$, $p = .084$, $d = 0.23$. Memory accuracy did not significantly improve with age in either the younger (4-5 years) or older (6-7 years) age group, $r_{Older}(103) = .01$, $p = .958$, $r_{Younger}(62) = .23$, $p = .069$ (note that analyses are performed separately due to differences in stimuli presentation for the two groups). Perceptual accuracy improved in both the older age group, $r(103) = .24$, $p = .013$, and younger age group, $r(62) = .36$, $p = .003$.

Metacognitive Abilities

Next, we examined whether children's confidence responses corresponded to their accuracy. As detailed below, several metrics for assessing metacognitive abilities have been proposed, with the hierarchical Bayesian estimation of group-level MRatio considered current best practice. To our knowledge, this is the first study using this metric and other common metrics (e.g., meta-d' and MRatio estimated through MLE) with children this young. Therefore, we preregistered these 'best practice' metrics alongside a common metric from the developmental literature to provide a complete picture of children's performance. We report all metrics below for posterity.

Confidence choices (2 = high confidence, 1 = medium confidence, 0 = low confidence) were averaged separately for items that children answered correctly and incorrectly. A 2 (Correct, Incorrect) by 4 (Age 4, 5, 6, 7) mixed ANOVA found that children at all ages reported higher confidence on correctly-answered Memory items than on incorrectly answered Memory items, $F(1, 128) = 25.15$, $p < .001$, $\eta_p^2 = 0.16$, with no effects of age or their interaction, ps > .135, see Figure 2. An analogous ANOVA on Perceptual items found the same main effect of accuracy on confidence choices, $F(1, 134) = 24.88$, $p < .001$, $\eta_p^2 = 0.16$. This effect was qualified by a marginal interaction between accuracy and age, $F(3, 134) = 2.44$, $p = .067$, $\eta_p^2 = 0.05$. Exploratory pairwise post hoc t tests (Bonferroni-corrected) found that the difference in confidence between correct and incorrect answers on Perceptual items was significant in 5 -7-year-olds, but not for 4-year-olds. There was no main effect of age on Perceptual confidence, $p = .139$. Therefore, consistent with past work using this metacognitive measure, we found that children's confidence reports were largely calibrated to their accuracy (Hembacher & Ghetti, 2014).

As has been extensively highlighted in several recent papers (Fleming, 2017; Maniscalco & Lau, 2012), indexes of metacognitive calibration such as the difference between confidence scores on correct and incorrect items capture information about three separate factors: the participant's metacognitive sensitivity (their ability to tell apart states of certainty), their metacognitive bias (their tendency to prefer to say high or low confidence), and their first-order task abilities.

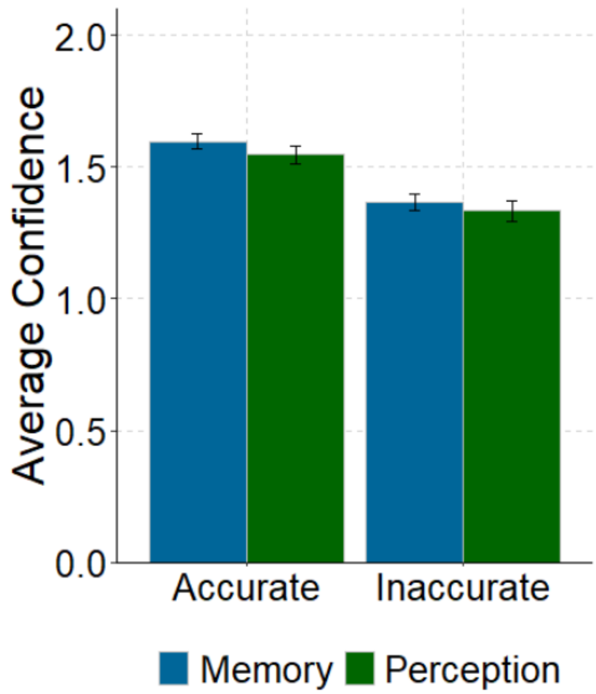

Figure 2: Average confidence (2 = high, 1 = moderate, 0 = low) on accurate (dark bars) and inaccurate (light bars) trials in the Memory and Perception tasks. Error bars = 1 SE.

We therefore turned to the meta-d' framework to compute additional measures of metacognitive performance. Briefly, meta-d' can be thought of as the amount of information about the first-order decision available for metacognitive reasoning. Children with good metacognitive sensitivity, who are very good at distinguishing when they are right from wrong, will have higher meta-d' estimates (see Fleming & Lau, 2014; Maniscalco & Lau, 2012 for more detailed descriptions). Meta-d' can also be directly compared to d' (the participant's sensitivity to the first-order task), yielding a measure of metacognitive efficiency, or how much information about the decision was available to the metacognitive system relative to how much was involved in actually making the decision. Metacognitive efficiency, or the MRatio, is thereby optimal at a value of 1 (all information used to make the decision was available to the metacognitive system). Below 1, the MRatio signals a loss of information from the decision to the metacognitive judgment, above 1, the MRatio signals additional information available to the metacognitive decision (e.g., realizing one made a mistake). Together, these two scores tell us how good a child's metacognitive abilities are without being influenced by their biases to report high or low confidence, and how good these abilities are relative to their first-order performance.

We relied on two techniques to model meta-d' and MRatio in our sample. First, we used the standard meta-d' toolkit (http://www.columbia.edu/~bsm2105/type2sdt/, Maniscalco & Lau, 2012) to model these two scores, which uses Maximum Likelihood Estimation with each subject's data individually. As is custom, all values in the model were

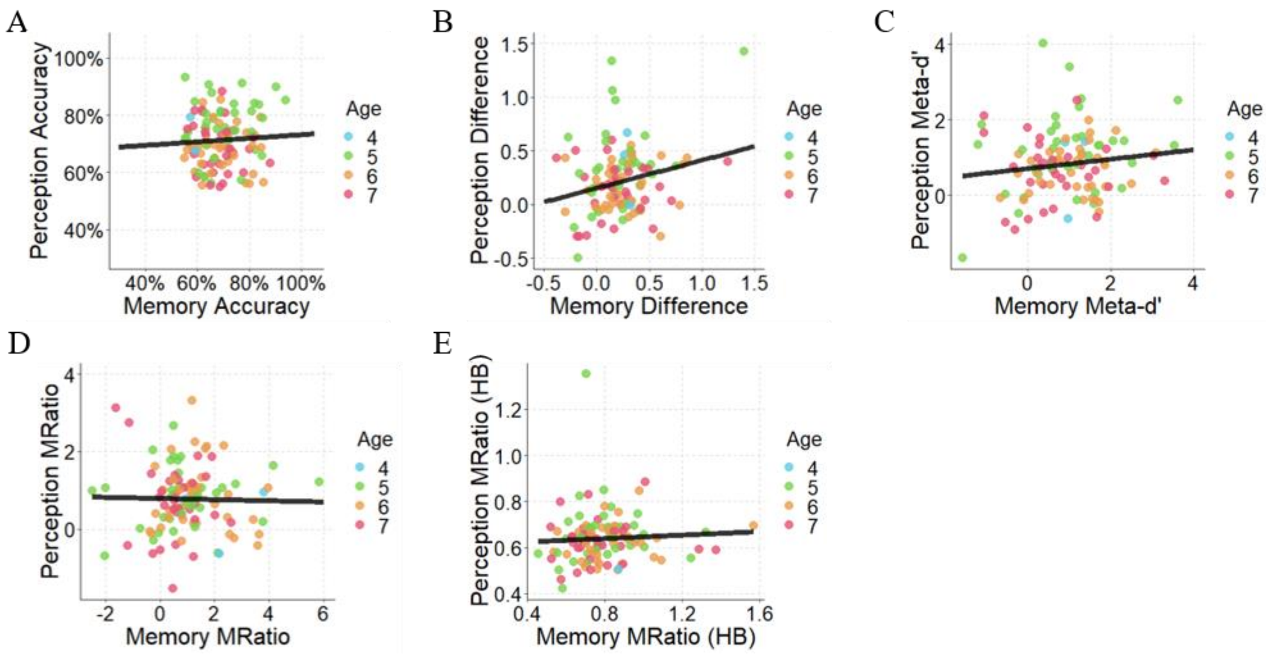

Figure 3: Correlations between (A) Accuracies in the tasks, (B) Differences in average confidence for accurate and inaccurate trials in the tasks, (C) Meta-d' estimates in the tasks, (D) MRatio (estimated through MLE) on the tasks, and (E) Individual estimates for MRatio (estimated through a hierarchical Bayesian model) on the tasks.

'edge-corrected' (i.e., slightly inflated to avoid involving zeros in the calculations). Meta-d' estimates of Memory (M = 0.94, SD = 0.99) were significantly above chance of 0, $t(107) = 9.84$, $p < .001$, $d = 0.95$, as were meta-d' estimates of Perception (M = 0.83, SD = 0.89), $t(107) = 9.69$, $p < .001$, $d = 0.93$, indicating the presence of metacognitive abilities. MRatio scores for Memory (M = 1.02, SD = 1.30) were not significantly higher than Perception (M = 0.78, SD = 0.86), $t(107) = 1.57$, $p = .119$, $d = 0.22$.

Second, we used a hierarchical Bayesian model to estimate group-level MRatio. As discussed in Fleming (2017), meta-d' estimates are influenced by low numbers of trials (e.g., 32 in each task in our study), and requiring edge-correction is not ideal for getting pure estimates of ability. In contrast, a hierarchical Bayesian model captures uncertainty around each single subject's estimate and accounts for this in the estimate of the group-level statistic. Using the HMeta-d' toolkit (https://github.com/metacoglab/HMeta-d, Fleming, 2017), the Memory MRatio was 0.70, 95% HDI [0.53, 0.88], and the Perception MRatio was 0.58, 95% HDI [0.43, 0.73], slightly lower than meta-d' estimates using MLE.

Correlations Between Metacognitive Abilities

We verified whether there was a correlation between Memory and Perceptual accuracy and found that these measures were not correlated in either age group (controlling for age), $r_{\text{Older}}(101) = .08$, $p = .45$, $r_{\text{Younger}}(37) = .12$, $p = .460$, see Fig. 3, suggesting that there were no obvious ways in which associations between first-order task performance may lead to spurious associations at the metacognitive level.

We computed the correlation between children's Memory and Perceptual metacognition performance using the four measures described previously: difference scores of average confidence (confidence on correct minus confidence on incorrect), meta-d', MRatio estimated through MLE, and MRatio estimated through hierarchical Bayes. Because the domain-specificity hypothesis relies on supporting the null hypothesis, we also preregistered conducting these correlations under a Bayesian framework where possible to quantify support for the null hypothesis. As explained in detail elsewhere (Wagenmakers et al., 2018), Bayesian analyses quantify the likelihood of one hypothesis over another in the form of a Bayes factor. All Bayesian analyses were conducted in JASP with the default prior.

Difference scores in Memory and Perception correlated, $r(108) = .23$, $p = .014$, and the Bayes factor (BF_{10}) indicated that a correlation was 2.59 times more likely than no correlation, (i.e., "anecdotal" evidence, Wagenmakers et al., 2018)[1]. Meta-d' scores did not correlate, $r(106) = .14$, $p = .153$, $BF_{01} = 3.04$, nor did MLE-estimated MRatios, $r(106) = -.02$, $p = .817$, $BF_{01} = 8.09$, with both Bayes factors indicating that evidence was moderately in favor of no correlation. Similarly, the 95% HDI on the posterior correlation coefficient of the hierarchical Bayesian MRatios overlapped

[1] Note that this correlation is heavily influenced by one child who had unusually high difference scores on both measures. Removing this child drops the correlation to $r(107) = .10$, $p = .303$.

0, ρ = .38, 95% HDI [-0.15, 0.57], indicating it was not different from the null hypothesis of no correlation. See Fig. 3 for graphs of the correlations.

Discussion

We found no correlation between episodic memory and perceptual confidence reasoning on 3 of 4 metrics in children aged 4-7. This is largely consistent with past correlational studies in children in other domains, and somewhat in contrast with a recent study using the same domains and methods of quantifying metacognition. These results, using a large sample of children and the current best practice metrics of metacognitive sensitivity, support a view of metacognition as an initially domain-specific process in these two domains episodic memory and perception.

We chose two cognitive domains from Mazancieux et al.'s (2020) paper showing domain-generality in adult metacognition that could easily be adapted to for examination in child samples. However, it is important to note that these domains had the weakest correlation in their paper. This potentially suggests that metacognition is not truly domain-general across all cognitive domains, even if it is domain-general among some cognitive domains. Given that we did not include an adult sample to replicate the original findings , we cannot rule out the possibility that we would also fail to demonstrate an association between metacognitive skills in the age group with the specific tasks used here. Relatedly, we cannot say for certain that our findings demonstrate a shift from domain-specificity in childhood to domain-generality in adulthood, though they are consistent with such a possibility.

How do we reconcile these findings with the compelling theoretical argument that confidence representations correspond to domain-general units, even in childhood? That is, does a lack of correlation between metacognitive sensitivity across domains necessitate that the confidence representations used in these metacognitive judgments are domain-specific?

At present, there is very little evidence for a domain-general unit of confidence between memory and perception, though there is growing evidence for a domain-general unit between different perceptual tasks. In one study using three perceptual tasks, 6-7-year-old children were flexibly able to compare their confidence both within and across tasks, signaling the presence of a domain-general unit of perceptual confidence even in childhood (Baer & Odic, 2020). However, many studies in both adults and children have found strong correlations between metacognitive abilities in perceptual tasks like these (e.g., Baer et al., 2018; Rouault et al., 2018), suggesting that perceptual confidence judgments might share underlying processing. As noted above, there are some domains that do not consistently show high correlations, including episodic memory and perception, making these domains ideal for testing whether confidence truly shares a domain-general unit. Directly testing whether children can compare their confidence between memory and perception, or whether confidence in one domain leaks into the other will be crucial for testing this possibility.

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