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The development of visual cognition: The emergence of spatial congruency bias

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Abstract

In adults, spatial location plays a special role in visual object processing. People are more likely to judge two sequentially presented objects as being identical when they appear in the same location compared to in different locations (a phenomenon referred to as Spatial Congruency Bias [SCB]). However, no comparable Identity Congruency Bias (ICB) is found, suggesting an asymmetric location-identity relationship in object binding. What gives rise to this asymmetric congruency bias? This paper considered two possible hypotheses. Hypothesis 1 suggests that the asymmetric congruency bias results from an inherently special role of location in the visual system. In contrast, Hypothesis 2 suggests that the asymmetric congruency bias is a product of development, reflecting people's experience with the world. To distinguish the two hypotheses, we tested both adults' and 5-year-old children's SCB and ICB by Identity Judgment Experiments and Spatial Judgment Experiments, respectively. The study found that adults only exhibited a SCB, but no ICB. However, young children exhibited both SCB and ICB, suggesting a symmetric congruency bias and reciprocal influences between location and identity in early development. The results indicate that the asymmetric location-identity relationship develops as object identity's influence on location gets pruned away, while location's influence on identity is preserved, possibly due to people's gained experiences with regularities of the world.

KEYWORDS
feature-binding, object recognition, object-location binding, spatial congruency bias, spatial location, visual cognition development

Research Highlights

1. Adults exhibit Spatial Congruency Bias—an asymmetric location-identity relationship with location biasing their judgment of object identities, but not vice versa.

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2. Asymmetric congruency bias may result from an inherently special role of location in visual system (Hypothesis 1) or accumulated experiences with the world (Hypothesis 2).
3. To distinguish the two hypotheses, the study investigated the Spatial Congruency Bias and Identity Congruency Bias in both adults and 5-year-old children.
4. Unlike adults who exhibited only Spatial Congruency Bias, 5-year-old children exhibited both Spatial Congruency Bias and Identity Congruency Bias.

1 | INTRODUCTION

Objects possess multiple properties such as location, color, shape, and texture. However, not all object properties are created equal. Much of previous research has demonstrated a special status of location and an asymmetric relationship between location and other object properties in visual perception and cognition. According to the Feature Integration Theory (Treisman & Gelade, 1980; Treisman & Zhang, 2006), for example, localizing objects is necessary for the correct and coherent integration of other features, which suggests the privileged role of location in object recognition. Consistently, various models of object processing (including object file and object index models) propose that attention to location is critical to creating object representation (Kahneman et al., 1992; Leslie et al., 1998; Scholl, 2001). Moreover, some of these theories maintain the principle of spatiotemporal priority (Flombaum & Scholl, 2006; Flombaum et al., 2009). The principle suggests that spatiotemporal information was privileged in object correspondence such that objects maintaining spatiotemporal continuity tend to be perceived as unchanged regardless of their featural properties. By contrast, when spatiotemporal contiguity is violated (i.e., object identity was changed from one retinal position to another after a saccade), object recognition is disrupted (Cox et al., 2005).

Furthermore, compared to other properties, location information is preferentially attended to, spontaneously processed, better memorized, and automatically encoded even when it is task-irrelevant (Boduroglu & Shah, 2009; Z. Chen, 2009; H. Chen & Wyble, 2015, 2016; Golomb et al., 2014; Tsal & Lavie, 1993). For instance, Z. Chen (2009) tested whether attending to a relevant dimension of stimulus would necessarily lead to the processing of other irrelevant dimensions. The results revealed that only location processing was involuntary and independent of task relevancy. In contrast, other dimensions (i.e., color and texture) were not necessarily processed when stimulus location was attended to.

Studies on visual selective attention have also supported the prioritized role of spatial location over other object properties (Harter et al., 1982; Hillyard & Münte, 1984; Johnston & Pashler, 1990). For example, using a target detection paradigm, Hillyard and Münte (1984) found that subjects' selection for object location preceded selection for color, and their selective attentional processing of color was contingent on the prior selection of location. However, the processing of object location was independent of the selection of color.

A more recent striking example of the asymmetric relationship between object location and other properties is the Spatial Congruency Bias (SCB) (Golomb et al., 2014). The SCB refers to the phenomenon where people are more likely to judge two sequentially presented objects as being identical when they appear in the same location compared to in different locations. In other words, the SCB represents a relative difference in response bias, (i.e., a relatively greater "same identity" bias for the same location condition than different location condition). This location effect has been reliably replicated with diverse types of stimuli, including abstract objects, colored squares, letters, faces, and facial expressions (Cave & Chen, 2017; Finlayson & Golomb, 2016; Shafer-Skelton et al., 2017; Starks et al., 2020). However, there does not appear to be an analogous Identity Congruency Bias (ICB): people are not more likely to judge two sequentially presented objects as having the same location when they share the same identity (Golomb et al., 2014).

Furthermore, the SCB is so robust that it was preserved even under strong opposing statistical regularities; in Babu et al. (2023), objects were manipulated in a way that they were much more likely to have different identities when presented in the same location, yet the original SCB persisted. Moreover, the SCB appears to bias object perception in an implicit way, not as a result of conscious strategic guessing. This suggests that once it is ingrained, it is very difficult to suppress (Babu et al., 2023). Accordingly, the SCB may present a challenge to theories of position-invariant object representations (e.g., Wallis & Rolls, 1997), but is consistent with more nuanced views of position tolerance (Cox et al., 2005; Cox & DiCarlo, 2008; DiCarlo & Cox, 2007; Golomb et al., 2014; Kravitz et al., 2010), in which object representations partially generalize across locations but some location-specificity is preserved.

Critically, the SCB—and lack of analogous ICB—suggests a special role of location in biasing people's perceptual judgment of other object properties. What gives rise to this asymmetric location-identity relationship? Is this special role of location in visual object processing something that is inherent in the visual system, such that the asymmetry is present from a very young age and relatively constant across the post-infancy human lifespan? Or is the asymmetry a product of development that emerges as a result of experience with the world?

Hypothesis 1. Location is inherently special in the brain

According to the first hypothesis, the asymmetric congruency bias between location and identity is due to an inherently special role of location in the human visual system. An extensive body of research has demonstrated that visually-sensitive neurons exhibit spatial sensitivity (Hubel & Wiesel, 1962), with location information persisting into higher-level visual areas that process complex object properties (DiCarlo & Maunsell, 2003; Golomb & Kanwisher, 2012; Kravitz et al., 2010; Op De Beeck & Vogels, 2000). Several studies have also revealed the existence of topographic maps of spatial location throughout the brain, from primary visual cortex (Engel, 1997), to higher level ventral and dorsal visual areas, such as ventral occipital cortex (Arcaro et al., 2009; Brewer et al., 2005), parietal cortex (Schluppeck et al., 2005; Sereno et al., 2001; Silver et al., 2005; Silver & Kastner, 2009), and frontal cortex (Silver & Kastner, 2009), which could underlie the behavioral findings discussed above and below, suggesting that the encoding of location information is necessary and automatic when identifying objects (H. Chen & Wyble, 2015, 2016; Harter et al., 1982; Hillyard & Münte, 1984; Johnston & Pashler, 1990; A. M. Treisman & Gelade, 1980; Tsal & Lavie, 1988, 1993).

In addition, behavioral results from studies investigating object recognition in early development have yielded ample evidence that infants in general were more likely to encode, represent, and prioritize spatial information over featural information such as color, shape, and/or identity, implying location information is favored in very early development (Ayzenberg et al., 2021; Kibbe & Leslie, 2011; Xu & Carey, 1996). And finally, topographical maps of spatial location are present in newborn non-human primates (Arcaro & Livingstone, 2017, 2021), 5-month-old infants (Ellis et al., 2020), and young children (Dekker et al., 2019), suggesting the existence of robust spatial information from early development, though it is unknown if this precedes or dominates the neural development of non-spatial information. Taken together, the reviewed evidence suggests that the SCB could simply be a manifestation of this neural prioritization, and we would expect it to be present early in development, with young children exhibiting the same asymmetric congruency bias pattern as adults.

Hypothesis 2. Spatial Congruency Bias is a product of development

According to the second hypothesis, the SCB emerges during childhood development as individuals gain more experience with the world and implicitly learn the regularities of the world. In the real world, spatiotemporal contiguity is a usually more reliable cue for object recognition than the reverse (Gao & Scholl, 2010; Yi et al., 2008). For example, when your cat is sleeping next to you, it is very unlikely that it will suddenly become a different cat. But it is possible that it will run to a different spot the next moment. Therefore, humans may learn from their experiences that location is a more reliable cue to judge object identity, but object identity is not always reliable to judge locations.

If the SCB is shaped by these long-term visual experiences, then we would expect the location-identity asymmetry to increase over time, such that the asymmetric congruency bias would be present in adults but not young children. We consider two possible ways this asymmetry could develop: (a) young children could exhibit neither a Spatial nor an Identity Congruency Bias, with the SCB developing as location is endowed with a privileged role during development; or (b) young children could exhibit both a Spatial and an Identity Congruency Bias, with the ICB getting pruned away over time.

According to the first developmental mechanism, location and identity may start off as being processed separably in early childhood, such that one dimension has minimal impact on perception of the other. A separable relationship between location and identity in early development is supported by reduced functional connectivity between two anatomically segregated and functionally independent parallel pathways for processing object identity and location (Goodale et al., 1991; Goodale & Milner, 1992; F. Newcombe et al., 1987; Ungerleider & Haxby, 1994), and difficulty with identity-location binding in infants and young children (Lorsbach & Reimer, 2005; N. Newcombe et al., 1999; Oakes et al., 2006).

On the contrary, location and other object properties (i.e., identity) could start off as being "fused" and reciprocally influencing each other, and in the course of development, identity's influence on location gets pruned away, but location maintains its influence on identity. A "fused" relationship between location and identity in early development gains support from findings that infants and children tend to process holistically the dimensions that appear separable for adults (Barrett & Shepp, 1988; Dobkins, 2005; see Hanania & Smith, 2009 for review; Smith & Kemler, 1978). In addition, fused relationship and reciprocal effects between location and identity in early development could stem from young children's immature selective attention and inhibitory control, as they have difficulty only focusing on task-relevant information while filtering out irrelevant information (Enns & Akhtar, 1989; Hagen & Hale, 1972; Hale & Alderman, 1978; Lane & Pearson, 1982; Plebanek & Sloutsky, 2017, 2018). By this mechanism, the dimensions are fused and decoupling of dimensions is a product of development. However, perhaps due to the discussed above special status or gained experiences with the world, location maintains its privileged status into the adulthood, thus affecting processing of other dimensions.

Current study

To distinguish among these hypothetical possibilities, we conducted four experiments with adults and 5-year-old children. Specifically, to measure the SCB, we tested adults and children on an Identity Judgment Task (modified from the original Golomb et al., 2014 task to be more child friendly) where participants judged whether two sequentially presented stimuli were the same object, and we assessed the influence of task-irrelevant object location. To measure a potential ICB, we tested adults and children on a Spatial Judgment Task where participants judged whether two sequentially presented stimuli were in the same location, and we assessed the influence of task-irrelevant object identity.

Here we focus specifically on the Congruency Bias effect, which is independent from other potential measures of task-relevant influence such as task accuracy/sensitivity and reaction time (Golomb et al., 2014). While sensitivity measures the overall accuracy in detecting targets, congruency bias represents the relative shift in decision criteria during judgments on one dimension (i.e., identity), influenced by matching versus mismatching irrelevant dimension (i.e., location), and thus carries unique theoretical significance, reflecting not simply a change

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in overall performance, but a bias towards a particular type of perceptual error (Golomb et al., 2014). Moreover, because congruency bias is measured as a relative shift in bias between two within-subject conditions, it is also independent from individual or age-related differences in absolute response bias that could reflect participants' overall tendency to favor either "same" or "different" responses, making it a particularly well-suited measure for comparisons across age groups.

For adults, we expected to replicate previous findings of an asymmetry between the two types of congruency bias: adults would only exhibit SCB, but not ICB. The critical question was whether young children would exhibit Spatial and/or Identity Congruency Bias, with the goal of understanding which theoretical mechanism shapes the asymmetric interaction between object location and identity in development.

1.1 | General method

1.1.1 | Participants

Adult participants were undergraduate students (age range: 18–22 years) at the Ohio State University who participated for course credit. Child participants (5-year-olds) were recruited from Columbus metropolitan area. Due to the COVID-19 pandemic, the study was conducted online. In all reported experiments, all adult participants and parents of child participants provided informed consent according to The Ohio State University Institutional Review Board.

Sample size for all experiments was determined based on power analyses of the original SCB study (Golomb et al., 2014). The prior study had a sample size of $N = 16$ and an effect size of $d = 1.01$. The power $(1 - \beta)$ to detect such an effect with the same sample size at 0.05 significance level (α) is 0.965. However, given that our sample included 5-year-old children whose data were anticipated to be noisier than adults, we decided to double the sample size used in Golomb et al.'s (2014) study to $N = 32$ for all experiments; additional participants were recruited as needed to replace participants excluded for poor performance (defined as overall task accuracy < 0.55, hit rate < 0.5, and/or false alarm rate > 0.5[1].

We conducted four experiments in total. Final sample of Identity Judgement Experiment with adults included thirty-two young adults (15 females, 17 males; Age: $M = 19.31$, $SD = 0.95$[2]). Final sample of Identity Judgment Experiment with children included thirty-two 5-year-olds (15 girls, 17 boys; Age: $M = 5.44$, $SD = 0.25$), including 18 White (56.25%), 2 Black or African American (6.25%), 1 Asian (3.125%), and 3 Multiracial (9.375%). In addition, there were 8 (25%) child participants whose parents did not report their race or ethnicity. Final sample of Judgment Experiment with adults included thirty-three young adults (15 females, 18 males; Age: $M = 19.15$, $SD = 1.11$[3]), and final sample of Spatial Judgment Experiment with children included thirty-two 5-year-olds (15 girls, 17 boys; Age: $M = 5.42$, $SD = 0.28$), including 22 White (68.75%), 3 Black or African American (9.375%), 2 Asian (6.25%), and 4 Multiracial (12.5%). In addition, there was one (3.125%) child participant whose parents did not report the child's race or ethnicity. Ten additional adult participants and four additional child participants in the Identity Judgment experiments, and nine additional adult participants and ten additional children in the Spatial Judgment experiments completed the experiments but were excluded from data analyses due to poor performance. Note that adult exclusion rates may have been higher than prior studies because these were online studies.

1.2 | Stimuli and procedure

1.2.1 | Task overview

Four experiments were conducted in total: Identity Judgment Experiment with adults, Identity Judgment Experiment with children, Spatial Judgment Experiment with adults, and Spatial Judgment Experiment with children. However, the four experiments were not run simultaneously: the Identity Judgment Experiments were run for both age groups first, and the Spatial Judgment Experiments were run after we collected data for Identity Judgment Experiments.

We used the Gorilla Experiment Builder (www.gorilla.sc) to create and host our experiment (Anwyl-Irvine et al., 2019). For adult participants, the link and instructions of the experiment were provided in a scheduled instructional Zoom meeting, and adult participants completed the experiment on their own devices (laptop or desktop). Child participants were tested by an experimenter via a scheduled Zoom experiment session during which an experimenter started the experiment on a laboratory laptop and shared the screen with the child. Unlike adults who responded by pressing the keyboard themselves, children responded by responding verbally, with the experimenter entering their answer on the keyboard.

In the Identity Judgment Experiments, participants were asked to make same/different judgment on identities of two sequentially presented stimuli, whereas in the Spatial Judgment Experiments, participants were asked to make same/different judgment on stimulus locations. In both tasks, participants were first instructed to perform a practice block (16 trials) to be familiarized with the task. Their performance in the practice block was not included in the analyses. Then, adults were presented with 10 testing blocks, whereas children were presented with 5 testing blocks (16 trials per block). To equalize the number of trials in the analyses, we only included adult participants' trials of the first five testing blocks.

On each trial, participants were shown two sequentially presented stimuli, and instructed to decide whether the stimuli were identical or different with respect to the target dimension (i.e., identity or location). In the Identity Judgment Experiments, the target dimension was object identity, and participants' task was to report "same" only when the two objects' identities matched exactly. Stimulus location was completely irrelevant in the Identity Judgment Experiments. In contrast, in the Spatial Judgment Experiments, the target dimension was object location, and participants' job was to report "same" only when the two objects appeared in the same exact location. Stimulus identity was completely irrelevant in the Spatial Judgment Experiments.

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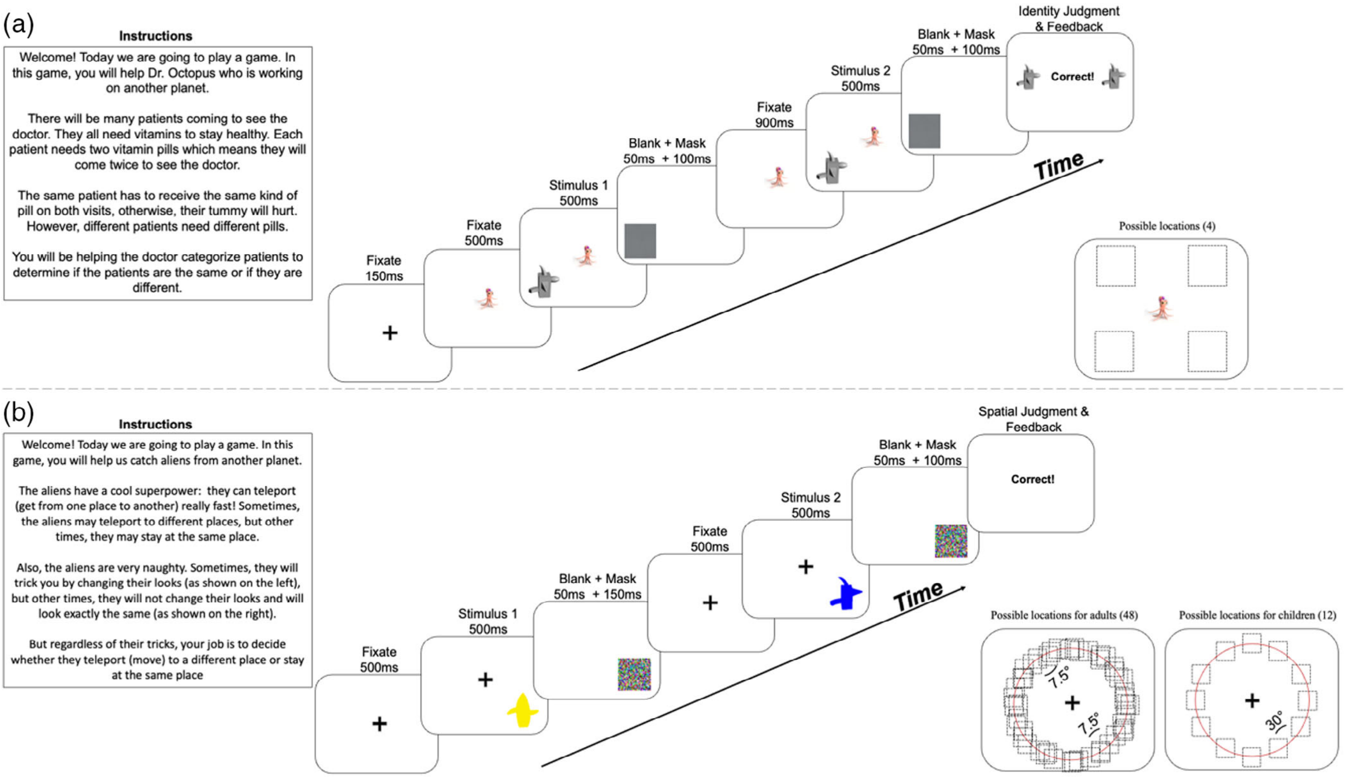

FIGURE 1 (a) A sample trial of the Identity Judgment Experiments is illustrated. Participants judged whether the identity (shape) of the two stimuli were the same or different. Stimulus location was irrelevant to the task. The four possible locations are shown at the bottom right. To make the task more child-friendly, a cover story was used to give instructions (see inset), and the octopus image was used as the fixation cue: it flashed off and on before each stimulus to bring fixation back to center of the screen. Both stimuli and octopus appear bigger than in the actual experiment. (b) A sample trial of the Spatial Judgment Experiments is illustrated. Participants judged whether the spatial location of the two stimuli were the same or different. Stimulus identity (shape, color) was irrelevant to the task. On different-location trials, the stimuli appeared in adjacent locations along an equal-eccentricity circle (closer distances in adults' version than children's version, shown at the bottom right; degrees are angular degrees along the circle).

1.2.2 | Stimuli

For the Identity Judgment Experiments, stimuli were the same grayscale abstract shapes as used by Golomb et al. (2014). Their stimuli were initially modified from the Tarr stimulus set (http://www.tarrlab.org/) by selecting 10 pairs of stimuli and creating a sequence of morphed images between each pair. In the current study, we only used the 0% and 100% morph level stimuli from each family (the most dissimilar pair within a family); therefore, our stimulus set had 10 families of abstract shapes, and each family contained 2 members. Stimuli could appear in one of four spatial locations (see Figure 1a).

For the Spatial Judgment Experiments, we used colored versions of the same stimuli. Each stimulus was filled with a solid color. Stimuli from the same family were filled with the same color. The 10 possible colors (one for each family) were: red, brown, yellow, green, cyan, blue, purple, salmon pink, gray, and black. We colored stimuli in the Spatial Judgment Experiments to increase identity differences, such that the task-irrelevant dimension would be comparably salient across tasks. In other words, in the Identity Judgment Experiments, the task-relevant dimension (identity) was perceptually challenging to discriminate, and the task-irrelevant dimension (location) was easily discernable. In the Spatial Judgment Experiments, the task-relevant dimension (location) was perceptually challenging to discriminate (small location differences of 7.5/30 angular degrees), and the task-irrelevant dimension (identity) was easily discernable.

1.2.3 | Identity judgment experiment procedure

We modified the original SCB Experiment (Golomb et al., 2014) to make it more child friendly (See Figure 1a). To make children more engaged in the experiment, we created a cover story about helping an alien doctor called Dr. Octopus to give correct vitamin pills to patients: each patient needs two vitamin pills, so they come twice to see the doctor; the same patient has to receive the same kind of pill, but different patients need different pills. So, participants' job was to help the doctor to determine if the patients were the same or different.

At the beginning of each trial, participants were instructed to fixate on a black fixation cross for 150 ms and then on a cartoon octopus' image in the center of the screen for 500 ms. We chose the cartoon octopus image because it would easily capture children's attention so it could help children fixate, and it fitted our cover story. Then, a stimulus

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would be presented in the periphery (upper left, upper right, lower left, or lower right of the octopus as shown at the bottom right of Figure 1) for 500 ms, followed by a blank screen (50 ms) and a mask (a concrete grey color square, 100 ms). Next, after a 900 ms delay (octopus image reappeared to capture attention back to central fixation), a second stimulus appeared for the same duration and masked as the first one.

On each trial, the two stimuli could be either identical or different object identities, and they could appear in the same or different spatial locations. The four conditions (Same Identity/Same Location; Same Identity/Different Location; Different Identity/Same Location; Different Identity/Different Location) were equally likely (4 trials per block). The first stimulus was always randomly selected from the stimuli pool, and it had equal chances of being presented at any of the potential locations. On Different Identity trials, for adults, the second stimulus was the other exemplar from the same family (a perceptually difficult task). For children, we used a modified (easier) version of the task where the second stimulus was randomly selected from a different family. On Different Location trials, one of the other three locations would be randomly selected for the second stimulus. Participants made two-alternative same/different judgment based on the identities of two stimuli and received feedback informing whether they were right or wrong. Verbal feedback was provided for children (e.g., “Correct! They were the same!”, “Oops! They were the same!,” etc.) and adults read the same feedback on the screen. The feedback was presented in the center, with the first stimulus presented on the left and the second stimulus presented on the right. Correct and incorrect feedback was also accompanied by different sounds: correct feedback was accompanied by an applause sound whereas incorrect feedback was accompanied by a voiced “oops” sound of a female voice.

To note, the major difference in the procedure between Identity Judgment Experiments with adults and children was the selection of the second stimulus on Different Identity trials. The task needed to be made easier for children to perform it accurately. Given this difference, we conducted two versions of the Identity Judgment Experiments in adults: one matched for difficulty (adults used same-family pairs on Different Identity trials), and the other matched for stimuli (adults used the child stimuli of different-family pairs on Different Identity trials). We report results of the difficulty-matched adult version in the main text, and results of the stimulus-matched adult version in Supplemental Experiment 1.

1.2.4 | Spatial judgment experiment procedure

For the Spatial Judgment Experiments, stimuli were colored (as described above), and could appear in a number of possible equidistant locations along an invisible circle (see Figure 1b). We added a screen calibration procedure at the beginning of the online task that allowed us to calibrate stimuli based on the size and distance of each individual subjects’ monitor so that the stimuli could be presented at approximately the same visual angle for all subjects (the calibration involved having participants hold a credit card up to their monitor at arm’s length). Possible stimulus locations were along the circumference of an invisible circle whose radius was 4.1 degrees visual angle. For children, there were 12 possible locations on the invisible circle with the adjacent locations being 30 angular degrees apart. For adults, we increased the task difficulty by having 48 possible locations with adjacent locations being 7.5 angular degrees apart. Different angular degrees for adults and children were adopted with an initial goal to match the task difficulty between the two age groups, as we did in the Identity Judgment Experiments. In practice we overcompensated in this effort, and the adults’ version ended up being more perceptually difficult than the children’s, as indicated by lower sensitivity found in adults compared to children (reported in Supplemental Materials). We discuss later in the paper why we did not consider this as a problem given the pattern of results we found.

In the cover story, children were told that their mission was to catch aliens. The aliens had a superpower which allowed them to teleport (get from one place to another) really fast and these aliens were naughty, so they sometimes changed their looks to trick children. Children’s job was to decide whether aliens teleported to a different place or stayed at the same place regardless of alien’s “tricks” (changing looks).

As shown in Figure 1b, at the beginning of each trial, participants were instructed to fixate on a black fixation cross in the center of the screen for 500 ms. Then, the first stimulus would be presented for 500 ms in a random location. After the first stimulus was presented, a blank screen showed for 50 ms followed by a colored mask presented for 150 ms. Next, after a 500 ms delay, a second stimulus appeared for the same duration, followed by a blank screen (50 ms) and a mask (100 ms). On each trial, participants were asked to make two-alternative forced choice same/different judgment comparing locations where the first and the second stimuli just appeared. After making a response, participants would receive feedback informing them whether they responded correctly.

Same as in the Identity Judgment Experiments, the two stimuli could be either identical or different objects, and they could appear in the same or different locations on each trial. The four conditions (Same Identity/Same Location; Same Identity/Different Location; Different Identity/Same Location; Different Identity/Different Location) were equally likely (four trials per block). The first stimulus was always randomly selected from the stimuli pool, and it had equal chances of being presented at any one of the candidate locations. On Different Location trials, the second stimulus appeared in one of the two locations adjacent to where the first stimulus was presented. On Different Identity trials, the second stimulus would always be a stimulus from a different family (so the two stimuli always differed in both color and shape).

Because stimuli from different families were different shapes and thus had potentially different centers of mass, there was concern that this could influence location judgments in the adult experiment (where adjacent stimulus locations were overlapping). To minimize this potential confound, we selected a subset of stimulus pairs with similar centers of mass to present in the Spatial Judgment Experiment with adults (details about stimulus pair selection and additional analyses can be found in Supplemental Analyses).

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1.3 | Analyses

Our analyses focused on the SCB and ICB. Trials on which participants responded with RTs greater than or less than 2.5 standard deviations of the participant's mean RT were excluded (less than 3.5% of trials for each experiment). To confirm that adults and children were able to perform the tasks and rule out the possibility that our results were simply due to low accuracy, we first ran a preliminary analysis (one-sample *t*-test) on adults' and children's overall accuracy. After demonstrating that both adults and young children showed above chance overall accuracy, our primary focus was on their SCB and ICB. Analyses of absolute response bias and sensitivity (d-prime) are provided as supplemental, independent measures. No further analyses were conducted with RTs because all of the experiments were conducted online, and more importantly, children's responses were collected by having experimenters record their spoken responses. Thus, RT data were not reliable for children.

The SCB and ICB were calculated following Golomb et al. (2014) and subsequent studies: First, for each participant and task condition, we used Signal Detection Theory to calculate the response bias:

$$Response\ bias = -\frac{z\,(hit\ rate) + z\,(false\ alarm\ rate)}{2} \quad (1)$$

Specifically, a hit was defined as a "same" response when the two stimuli matched on the target dimension (i.e., identity in the Identity Judgment Experiments and location in the Spatial Judgment Experiments), whereas a false alarm was defined as a "same" response when the two stimuli did not match on the target dimension.

For the Identity Judgment Experiments, we calculated response bias for each participant for the Same Location trials and Different Location trials. The SCB was then calculated as the difference in response bias between Same and Different Location trials by Equation 2. A positive SCB indicates participants are more likely to report two items as the same identity when they appeared in the same (compared to different) location. For the Spatial Judgment Experiments, we calculated response bias for each participant for the Same Identity trials and Different Identity trials. The ICB was calculated as the difference in response bias between Same Identity and Different Identity trials by Equation 3. A positive ICB indicates that participants are more likely to report two items as presented in the same location when they shared the identity.

$$SCB = -\left(Response\ Bias_{Same\ Location} - Response\ Bias_{Different\ Location}\right) \quad (2)$$

$$ICB = -\left(Response\ Bias_{Same\ Identity} - Response\ Bias_{Different\ Identity}\right) \quad (3)$$

We first analyzed the results of each experiment individually, to examine whether the within-subject SCB and ICB measures were significant in adults and children, using one-sample *t*-tests comparing these difference scores against zero (implying no congruency bias). Then we conducted a series of follow-up between- and across-experiment analyses to further understand age differences in both SCB/ICB and absolute response bias, with an acknowledgment that procedural differences between age and task may render between- and across-experiment analyses illegitimate. Specifically, we conducted an independent two-sample *t*-test to compare SCB and ICB within adults to see whether we could replicate the asymmetry reported by previous findings. We conducted an identical analysis to compare children's SCB and ICB. Moreover, a 2 (age: adults vs. children) × 2 (congruency bias type: SCB vs. ICB) factorial ANOVA was conducted to compare the four experiments. Follow-up mixed ANOVAs were conducted to examine potential different response bias patterns in adults and children. Bayesian *t*-tests and Bayesian ANOVAs were also conducted to provide further evidence using the ttestBF and anovaBF functions from the BayesFactor package in R (Morey, Rouder, & Jamil, 2014).

2 | RESULTS

2.1 | Preliminary analyses on overall accuracy

Our main theoretical question was focused on the SCB and ICB measures, but it was important to first verify that both the adults and children were able to perform the tasks. Overall, adults and children exhibited high accuracy in both Identity Judgment Experiments and Spatial Judgment Experiments. One-sample *t*-test revealed above-chance (0.5) mean accuracy for adults ($M = 0.778$, $SD = 0.082$), $t(31) = 19.208$, $p < 0.001$, $d = 3.40$, and children ($M = 0.775$, $SD = 0.816$), $t(31) = 19.042$, $p < 0.001$, $d = 3.37$, in Identity Judgment Experiments, and for adults ($M = 0.735$, $SD = 0.050$), $t(32) = 26.933$, $p < 0.001$, $d = 4.69$, and children ($M = 0.854$, $SD = 0.101$), $t(31) = 19.908$, $p < 0.001$, $d = 3.52$, in Spatial Judgment Experiments. Additional breakdowns of accuracy and sensitivity by condition can be found in the Supplemental Materials.

2.2 | SCB and ICB

Figure 2a shows adults' and children's absolute response bias measures by condition, and Figure 2b shows the calculated congruency bias scores, where the SCB reflects the influence of task-irrelevant spatial information on Identity Judgment Experiments and the ICB reflects the influence of task-irrelevant identity information on Spatial Judgment Experiments.

One-sample *t*-tests comparing adults' SCB and ICB against 0 revealed a significant SCB, $t(31) = 2.979$, $p < 0.01$, $d = 0.53$, but not an ICB in adults, $t(32) = -0.083$, $p = 0.935$, $d = -0.01$. One-sample Bayesian *t*-tests provided further evidence for the presence of SCB, $BF10 = 7.257$, and the absence of ICB, $BF10 = 0.187$, in adults.

In contrast, in 5-year-old children, we found both significant SCB, $t(31) = 3.625$, $p < 0.01$, $d = 0.64$, and ICB, $t(31) = 2.393$, $p < 0.05$, $d = 0.42$. One-sample Bayesian *t*-test provided strong evidence for SCB, $BF10 = 31.878$, and anecdotal evidence for ICB, $BF10 = 2.195$, in children.

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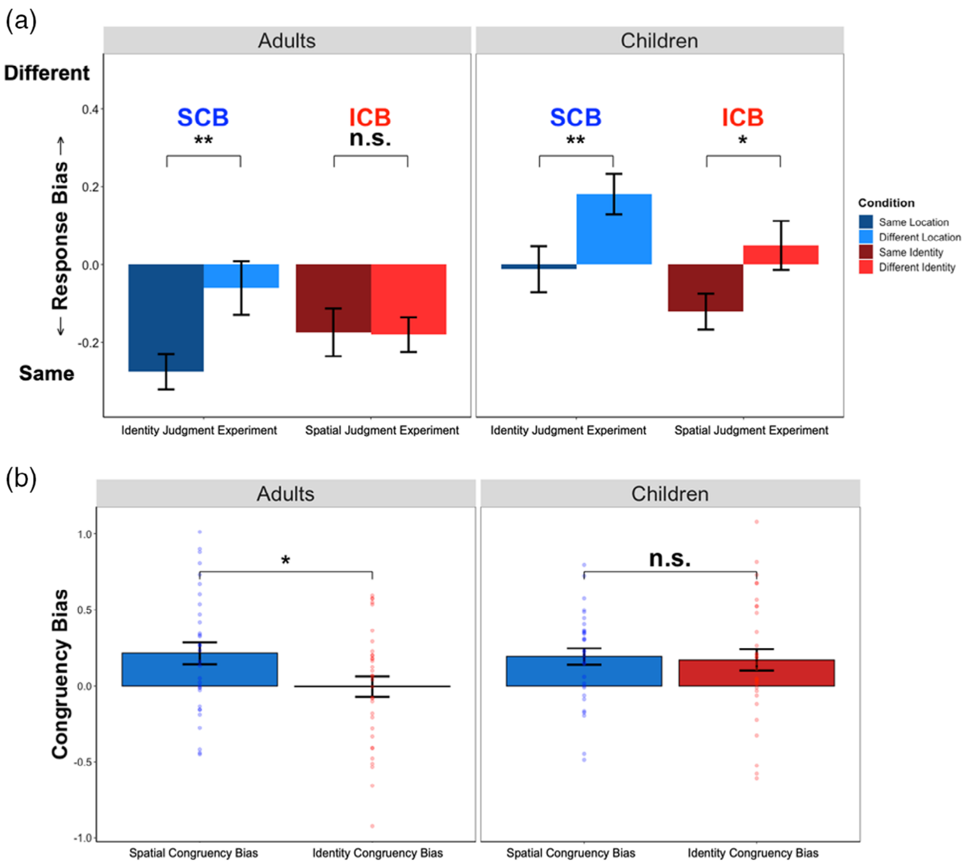

FIGURE 2 (a) Absolute response bias plotted for Same and Different Location/Identity trials, in the Identity Judgment Experiment and Spatial Judgment Experiment with adults (left), and Identity Judgment Experiment and Spatial Judgment Experiment with children (right). The more negative the response bias was, the more likely participants responded "same." The error bars represent standard errors. (b) Spatial Congruency Bias versus Identity Congruency Bias. The left figure shows SCB and ICB in adults, and the right figure shows SCB and ICB in children. The blue and red dots are individual subject data. The error bars represent standard errors.

2.3 | Congruency bias asymmetry in adults

To investigate whether adults showed asymmetric SCB and ICB as found in previous research, we conducted an independent two-sample *t*-test (Welch Two Sample *t*-test) to compare SCB and ICB across the two experiments with the adult age group. The results revealed that there was a significant difference between the two types of bias, $t(62.538) = 2.235$, $p = 0.0290$, $d = 0.56$ (yet $BF10 = 2.038$ was gained from Bayesian *t*-tests, providing anecdotal evidence for the difference between SCB and ICB across experiments).

2.4 | Congruency bias symmetry in children

An independent two-sample *t*-test (Welch Two Sample *t*-test) was also conducted to compare children's SCB and ICB. Unlike for adults, the results revealed no significant difference between these two types of congruency bias, $t(57.515) = 0.262$, $p = 0.794$, $d = 0.07$. In addition, two-sample Bayesian *t*-test lent moderately strong support for no difference between children's SCB and ICB, $BF10 = 0.263$.

2.5 | Across-experiment comparisons between adults and children

Although across-experiment analyses may not be appropriate given the substantial procedural differences across the experiments, we decided to conduct such analyses and treat them with caution. To that end, to further compare the asymmetric and symmetric congruency bias found in adults and children respectively, we conducted a 2 (age: adults vs. children) × 2 (congruency bias type: SCB vs. ICB) factorial ANOVA. The analyses revealed only a significant main effect of congruency bias type, $F(1, 125) = 5.554$, $p = 0.02$, $\eta^2 = 0.03$. The interaction between age and congruency bias type was not significant, $F(1, 125) = 2.204$, $p = 0.14$, $\eta^2 = 0.02$. Furthermore, according to the results of Bayesian ANOVA, model including the interaction had a Bayes factor of 0.646 relative to the model excluding the interaction.

2.6 | Absolute response bias in adults and children

Our main theoretical focus was on the congruency bias measures (relative difference in bias), as reported above. However, there may be other

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potentially interesting effects that vary across tasks and age groups. For example, participants may vary in their overall tendency to respond "same" or "different"; to examine this, we examined the absolute response bias for each condition across experiments (Figure 2a), with the same disclaimer as above, that comparisons across experiments be treated with caution.

Interestingly, in the Identity Judgment Experiments, although both adults and children exhibited a SCB of roughly similar magnitude, there were clear differences in terms of absolute response bias. Adults overall seemed to be more *overall* biased to respond "same identity", whereas children were overall more biased to respond "different identity". A 2 × 2 mixed ANOVA with age as a between-subject factor and location as a within-subject factor revealed significant main effects of both age, $F(1, 62) = 14.30$, $p < 0.001$, $\eta^2 = 0.19$, and location, $F(1, 62) = 20.71$, $p < 0.001$, $\eta^2 = 0.25$, but no interaction. The significant main effect of location suggested the presence of SCB, and the significant main effect of age suggested developmental changes in absolute bias (i.e., overall tendency to report "same" vs. "different"). However, again, interpretations of these results should be cautious, given that, due to procedural differences, between-experiment analyses may not be fully appropriate.

As for the Spatial Judgment Experiments, we also conducted a 2 × 2 mixed ANOVA with age as a between-subject factor and identity as within-subject factor. The results revealed a significant main effect of age, $F(1, 63) = 5.65$, $p = .02$, $\eta^2 = 0.08$, and non-significant effect of identity, $F(1, 63) = 2.83$, $p = 0.1$, $\eta^2 = 0.04$, and non-significant interaction, $F(1, 63) = 3.22$, $p = 0.08$, $\eta^2 = 0.05$. More analyses on absolute response bias can be found in the Supplemental Materials.

2.7 | General discussion

In the current study, we examined the visual location-identity interplay in adults and young children. Specifically, we examined the role of task-irrelevant location information (SCB) in an Identity Judgment Task, and the role of task-irrelevant identity information (ICB) in a Spatial Judgment Task. First, aligning with prior investigations, we replicated the asymmetry in location-identity interplay in adults by finding that location biased their identity judgment, but not vice versa (Golomb et al., 2014). Specifically, adults were more likely to judge two sequentially presented objects as being the same object when they appeared in the same location compared to different locations. However, shared identity did not have equivalent effects on adults' spatial judgment.

In contrast to adults, young children displayed both a SCB and ICB, indicating that congruency bias was not uniquely driven by object location at 5 years of age. We also emphasize that it was not simply a case of children showing more response bias than adults: if anything, the *absolute* response biases were larger for adults; it was just that the Congruency Bias was limited to SCB in adults. The results suggest fused processing and reciprocal influences between location and identity in early development, providing support for *Hypothesis 2* (the second mechanism in particular) which suggests that the asymmetric location-identity relationship develops as identity's influence on location gets pruned away.

The finding of SCB in both age groups provides further evidence against strict position invariance (no spatial influence) on object representation but is compatible with position tolerance arguments. Specifically, although increased position tolerance is found in higher order visual areas, spatial information is not entirely discarded from object representation across human development (Cox & DiCarlo, 2008; DiCarlo & Cox, 2007; Kravitz et al., 2010).

In addition, critically, our research was the first study that revealed the presence of both SCB and ICB in early childhood. First, despite previous evidence for a special role of location in early development (Ayzenberg et al., 2021; Kibbe & Leslie, 2011; Xu & Carey, 1996), our results demonstrated that Congruency Bias was not a uniquely location effect in early development. Instead, object identity can also bias children's perceptual judgment of other dimensions. Secondly, our finding revealed an important developmental change in visual cognition: a shift from a symmetric to an asymmetric location-identity relationship. The shift is characterized by two main processes: 1) pruning-away of ICB and 2) preservation of SCB. In what follows, we will discuss possible explanations for such a shift.

We suggest that the pruning-away of the ICB is probably due to the development of selective attention. There is ample evidence suggesting that young children have difficulty selectively attending to task-relevant information while filtering out irrelevant information (Deng & Sloutsky, 2015, 2016; Enns & Akhtar, 1989; Hagen & Hale, 1972; Hale & Alderman, 1978; Hanania & Smith, 2009; Lane & Pearson, 1982; Pastò & Burack, 1997; Plebanek & Sloutsky, 2017, 2018). The symmetric SCB and ICB in children may be driven by their immature selective attention and inhibitory control: they are unable to suppress the distraction of irrelevant location/identity information when making judgment on the target dimension (identity/location). For example, in the Identity Judgment Experiment, children might respond "same" when different stimuli appeared in the same location, because they could not exclusively focus on stimulus identity, and therefore were inevitably influenced by the congruity of the irrelevant location dimension.

However, as selective attention develops, people exhibit both increased focusing on relevant information and efficient filtering of irrelevant information. As a result, interference from irrelevant information gets weaker. Therefore, the pruning-away of ICB could be explained by increased selective attention skills and inhibitory control during development. However, a selective attention account alone would also predict a pruning-away of the SCB under the same logic. Why is the SCB resistant to pruning?

The SCB may maintain its influence on identity as people learn about visual regularities from their prior experiences. As discussed in the Introduction, location may be endowed with a special role as people interact with the world and implicitly learn the regularities of the world. Specifically, in the real world, objects sequentially viewed in the same place within a brief time period are likely to be the same identity. For example, sequential glimpses of a cat sitting on the same cat bed will most likely be the same cat. Therefore, after years of accumulated experience, people may implicitly form an assumption that objects presented in the same location are the same identity.

2.8 | Potential limitations

One potential limitation of the study is that all subjects (both children and adults) completed the experiments on an online platform using their own devices. This meant we had less control over the visual display and experimental environment. It also meant we did not use eye-tracking to monitor subjects' fixation as in the prior studies (Golomb et al., 2014; Finlayson & Golomb, 2016; Shafer-Skelton et al., 2017; Starks et al., 2020). For the Identity Judgment Experiment with adults, we tested an experimental eye-tracking functionality on Gorilla to collect gaze data utilizing WebGazer.js (Papoutsaki et al., 2016). However, the recording tended out to be unreliable, and as a result, we did not end up using it for any analyses. This lack of experimental control and eye-tracking would be expected to make our data noisier and thus, effects were expected to be hard to find unless they were strong. Importantly, we replicated the previously reported asymmetry between SCB and ICB in adults under these less ideal circumstances. Moreover, the fact that we found significant SCB and ICB in young children suggests that these effects were quite strong, and if anything, we may be underestimating their effect size. The increased noise in our experimental setups may also have contributed to some of the less reliable interactions between experiments.

Furthermore, our original intention was to match the tasks for difficulty across the age groups for in the Spatial Judgment Experiment, but determining the precise angular degrees for adults and children that can yield comparable levels of sensitivity (and overall accuracy) is very challenging, and children performed better than expected. We were prepared to run additional experiments with better matching if needed, but given the pattern of results, we determined this was not necessary. Importantly, while we recognize the benefits of having matched versions of the Spatial Judgment task, we do not believe that this difference in difficulty could explain our findings. Specifically, the Congruency Bias is typically more pronounced in more perceptually difficult tasks (when sensitivity is low). Because adults' sensitivity was lower than that of children (i.e., the adult version of the task was more difficult), that should make it more likely to see an ICB in adults than in children. However, we found the opposite pattern. If there hadn't been an ICB in children, or if children exhibited lower sensitivity than adults, it would have been important for us to conduct additional matched versions of the Spatial Judgment Experiment. Thus, the fact that, despite the disparity between the two versions, children (but not adults) exhibited ICB further strengthens our results.

2.9 | Future directions

In the current study we recruited 5-year-old children for our sample population, because they are old enough to follow the task instructions, yet some aspects of their visual cognition may still not be fully developed (Köster et al., 2017; Mondloch et al., 2002). However, 5-year-old children have already accumulated substantial experiences with the world. Our finding of symmetric SCB and ICB in this age group provides an important and novel benchmark, especially in contrast with the mature adult asymmetric relationship. Therefore, additional research is needed to elucidate the profile of location-identity interactions in object recognition in children substantially younger than 5 years of age and the developmental trajectory of these interactions.

Another interesting question worth exploring is what features drive the ICB in children. In our Spatial Judgment task, we made color a distinguishing cue that covaries with shape. Thus, we don't know if what we're calling an Identity Bias is actually a Shape Bias, a Color Bias, or a joint bias. In adults, spatial location biases both shape and color judgments, but neither shape nor color induced congruency biases (Golomb et al., 2014). Therefore, there remains an open question whether all object properties (e.g., color, shape, texture, etc.) can symmetrically bias judgments of each other in children, or if only certain properties can.

Last but not least, although we found a robust SCB in both adults and young children, there seemed to be age differences in their absolute bias. Specifically, adults exhibited an overall tendency to report "same", whereas children were more likely to report "different". Cave and Chen (2017) also reported different absolute bias when they investigated SCB using different tasks. Specifically, they found that tasks requiring analytical processing led to an overall bias towards "different" responses, whereas tasks requiring holistic processing led to an overall bias towards "same" responses. However, given that the same experiment instructions were provided for both age groups in our study, task demands failed to account for the age difference in overall response bias found in the current study. Future studies may thus also investigate what is underlying developmental changes in absolute (overall) response bias.

3 | CONCLUSION

The current research investigated the theoretical mechanisms underlying the asymmetric location-identity relationship found in adults during visual object recognition. By testing both SCB and ICB in adults and 5-year-old children, our results revealed an important developmental change in visual cognition: a shift from symmetric to asymmetric location-identity interactions. That is, although both location and identity tend to bias children's perceptual judgments about the other dimension, only the location dimension impacts adults' identity judgments. Such findings have several important implications. First, our results extend the previously reported interesting phenomenon — SCB, to a younger age group, demonstrating its early onset. More importantly, our results revealed that the congruency bias was not uniquely a spatial effect in early development. Our findings support the hypothesis that the asymmetric location-identity relationship (or the presence of only SCB) in adults is a product of development. Specifically, it surfaces as identity's influence on location gets trimmed away while location's influence on identity is robustly preserved. We further

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propose some possible explanations for the emergence of this asymmetric location-identity interaction. Future research is needed to gain a more fine-grained understanding of the developmental trajectory of the asymmetry and the mechanisms underlying the different forms of Congruency Bias.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All stimuli, data, and analysis code used for this article is available via the Open Science Framework and can be accessed via the link: https://osf.io/kmyu9/?view_only=11d6d3cccda44fe894df1e6bb8fa82a0

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ENDNOTES

[1] We adopted the same exclusion criteria as in the original SCB paper (Golomb et al., 2014). To ensure that our exclusion criteria did not affect our main results, we performed the same analyses on SCB and ICB by including all participants. The findings were consistent with our original results, except for negligible differences in the statistics values.

[2] Eight participants did not report their ages. The average age and standard deviation were calculated based on those who reported. In addition, Ethnicity/race of adult participants were not collected in the experiments.

[3] Five participants did not report their ages. The average age and standard deviation were calculated based on those who reported

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