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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
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Abstract

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Abstract

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Preschoolers rely on spatial cues to individuate objects

Whether to identify food or avoid harmful materials, object recognition is essential for survival (Santos, Hauser, & Spelke, 2001). Yet before we can recognize objects, we must first individuate them—that is, we must first establish which units within a scene constitute individual objects (Leslie, Xu, Tremoulet, & Scholl, 1998). Object individuation allows us to perceive the world not as an amorphous accumulation of visual input, but rather, as composed of discrete units. Specifically, individuation establishes the presence of object units and allows us to enumerate objects and track them across space and time (Leslie, Xu, Tremoulet, & Scholl, 1998; Uller, Carey, Hauser, & Xu, 1997). Importantly, establishing whether there is one or multiple objects involves encoding visual information, including spatial cues, such as distance, and featural cues, such as color and shape (Cheries, Newman, Santos, & Scholl, 2006). Yet questions persist about how humans use spatial and featural cues to individuate objects across development.

In the first four years of life, there is a profound shift in how children use spatial and featural cues in object perception (Ayzenberg, Nag, & Lourenco, 2017; Haun, Call, Janzen, & Levinson, 2006). Infants can extract an object's spatial properties, such as its location (Ayzenberg, Nag, & Lourenco, 2017; Newcombe, Huttenlocher, & Learmonth, 1999), as well as featural properties, such as its shape and color (Ayzenberg, Nag, & Lourenco, 2017; Wilcox, 1999). Yet when spatial and featural cues are presented simultaneously in an object detection task, infants have been shown to rely more on spatial than featural cues (Ayzenberg, Nag, & Lourenco, 2017; Huan, Call, Janzen, & Levinson, 2006). By contrast, preschool-aged children show the reverse pattern of responding such that, in a target detection task, they rely on objects' featural properties more than spatial properties (Ayzenberg, Nag, & Lourenco, 2017; Haun, Call, Janzen, & Levinson, 2006). What might account for this change in cue weighting?

One proposed explanation for this shift in cue weighting is language acquisition (Xu & Carey, 1996). Specifically, the proposal is that children's acquisition of vocabulary words may lead to a greater reliance on object features for individuation (Xu & Carey, 1996). Indeed, Xu and Carey (1996) found that, when individuating objects, prelinguistic 10-month-old infants only used objects' spatial properties (i.e., spatial separation between objects), whereas 10-month-old infants with vocabularies of at least two words used both objects' spatial and featural properties. This research suggested that, as children learn their first words, language acquisition caused the shift in object cue weighting (Xu & Carey, 1996).

However, research with nonhuman animals calls the language acquisition proposal into question (Uller, Carey, Hauser, & Xu, 1997). In particular, it has been shown that nonhuman primates (who do not have human language as part of their culture) are capable of individuating objects by both their features, as well as spatial properties (Uller, Carey, Hauser, & Xu, 1997) and do so spontaneously in the wild (Cheries, Newman, Santos, & Scholl, 2006). In fact, nonhuman primates display a bias towards the shape of functional objects, namely tools (Santos, Miller, & Hauser, 2003). These findings suggest that language is not a sufficient explanation for the developmental shift in the weighting of object properties. Rather, preschoolers' greater feature weighting may reflect the underlying attentional mechanisms of object perception (Smith, Jones, & Landau, 1996). Specifically, language may relate to feature weighting in that the act of labeling objects may direct children's attention to diagnostic features, such as shape. Thus, an alternative possibility is that the demands of the task influence how visual information is weighted. Specifically, it is possible that children's object processing shifts from object *individuation* in infancy, for which spatial cues are especially reliable, to object *identification* in preschool age, for which featural cues are especially reliable.

Object Individuation

Many studies have shown that spatial information is critical for object individuation, especially in infancy (Leslie, Xu, Tremoulet, & Scholl, 1998). Before 10 months of age, infants can only individuate two objects that are placed in separate locations but are unable to do so using features (Van de Walle, Carey, & Prevor, 2000; Xu & Carey, 1996; Xu, Carey & Welch, 1999). Even when infants become capable of individuating objects using features, such as shape and color, they continue to rely primarily on spatial cues (Leslie, Xu, Tremoulet, & Scholl, 1998; Needman & Kaufman, 1997; Xu & Carey, 1996; Xu, Carey & Welch, 1999). There is some evidence that 4-month-olds can use shape and size (but not color) to represent multiple objects through occlusion (Wilcox, 1999; Wilcox & Baillargeon, 1999). However, infants can do so only when there is one object presented at a time and when there are no spatial cues present. This raises the possibility that if spatial cues were presented in these paradigms, then infants might weight spatial cues more than features to individuate the objects.

Additional research sheds further light on the role of spatial cues in object individuation. Adults individuate objects by spatial cues (e.g. Spelke, Kestenbaum, Simons, & Wein, 1995), as well as features (e.g. Xu, Carey, & Welch, 1999), but automatically encode an object's spatial properties when making individuation judgments (Golomb, Kupitz, & Thieman, 2014; Mitroff & Alvarez, 2007). Brain regions known to be involved with object individuation, such as the posterior intraparietal sulcus (IPS), are primarily sensitive to the spatial properties of objects, not the featural properties (Xu, 2009). Moreover, patients with damage to the posterior parietal cortex have difficulty individuating objects and, as a result, are incapable of perceiving more than a single object at once – a disorder known as Balint's syndrome (Robertson, Treisman, Friedman-Hill, & Graboweky, 1997). These patients also show impairments in spatial processing and have trouble locating and grasping objects in their appropriate locations. Together, these findings emphasize the importance of spatial cues in object individuation. In fact, when there is too little spatial separation between objects, stimuli are more likely to be perceived as textures as opposed to multiple objects (Pelli & Tillman, 2008; Whitney & Levi, 2011).

Object Identification

Object identification requires the use of diagnostic features to determine the identity of an object (Biederman, 1987). Thus, featural cues may play a greater role in the process of object identification than in object individuation. Much work has emphasized the role of features, particularly shape, as indicative of object identity (Biederman, 1987; Op de Beeck, Torfs, & Wagemans, 2008). As children begin to explicitly identify objects beginning around 10 and 12 months of age, they are increasingly better at encoding objects' features (Westermann & Mareschal, 2014). Moreover, increases in feature weighting correlate with gains in children's ability to identify objects (Vlach, 2016). This may be interpreted as support for the role of language acquisition in driving the shift in object cue weighting. However, language, particularly object labeling, may drive attention towards objects' features because linguistic labeling entails identifying objects, a task for which featural cues are especially reliable (Smith, Jones, & Landeau, 1996; Leslie, Xu, Tremoulet, & Scholl, 1998). Indeed, 3-year-olds are biased towards shapes and generalize object names based on shape (Landau, Smith, & Jones, 1998).

Likewise, brain regions known to be involved in object identification, such as the inferior temporal lobe (IT), are more sensitive to featural cues than spatial cues (Grill-Spector, Kourtzi, & Kanwisher, 2001; Xu, 2009). Damage to the inferior temporal lobe has been shown to result in an impairment in perceiving object identity, but leaves object individuation intact (Behrmann & Kimchi, 2003). This suggests that featural cues, not spatial cues, are of particular importance for object identification.

These findings raise the intriguing possibility that infants highly weight spatial cues because they are primarily engaged in an object individuation task, for which spatial cues are more reliable. By contrast, older children have likely mastered object individuation and have now moved onto the task of object identification, for which featural cues are more reliable. It is possible that, before an object can be identified, it must first be individuated (Leslie, Xu, Tremoulet, & Scholl, 1998). At 5 months of age, infants are sensitive to changes in the number of objects but not to changes in features (Simon, Hespos, & Rochat, 1995). This may suggest that infants individuate multiple objects before identifying them (Leslie, Xu, Tremoulet, & Scholl, 1998). In addition, adults can individuate objects faster than they can identify them, suggesting that individuation could be occurring before identification (Sagi & Julesz, 1984). Likewise, models of object attention purport that objects are first individuated by their spatial locations and only later is featural information bound to the spatially individuated object (i.e., allowing it be recognized; Leslie, Xu, Tremoulet & Scholl, 1998).

Present Study

The present study examines the possibility that infants' weighting of spatial cues is related to the goal of object individuation, whereas 3- and 4-year olds' weighting of featural cues may relate to the goal of object identification (Leslie, Xu, Tremoulet, & Scholl, 1998). Indeed, Ayzenberg and colleagues (2017) found that infants and preschoolers performing matched target detection tasks exhibited opposite weightings for spatial and featural cues. Specifically, 12-month-old infants weighted spatial cues more heavily than featural cues, whereas preschoolers

(42 to 54 months) showed the opposite weighting. Although this task did not explicitly ask children to individuate or identify objects, the findings are consistent with the possibility that infants were implicitly engaging in object individuation, whereas older children were implicitly engaging in object identification.

If preschool children rely more on features because they are implicitly engaging in an object *identification* task, then when explicitly engaging in an object *individuation* task, they should reverse their cue weighting. Thus, the current study tested the possibility that object individuation would elicit greater spatial, as opposed to featural, cue weighting in preschool-aged children. Children were asked to determine the number of objects from visual displays that could be individuated by either spatial (i.e., spatial separation) or featural (i.e., color or shape) cues. Examining the conditions in which 3- and 4-year-olds weight spatial and features cues can help explain the development shift in object cue weighting between infancy and preschool age, as well as better reveal the mechanisms underlying visual cue combination in object perception. Cumulatively, this research informs how the visual system functions in this potentially critical period of change in the first four years of life.

Method

Participants

Thirty-seven children (13 girls) between 42 and 54 months of age (M = 4.00 yrs, range = 3.06 yrs – 4.59 yrs) participated in the study (4 children failed to meet inclusion criteria for analysis). Families were contacted through the Emory University Child Study Center Database by phone call and follow-up email. Parents or legal guardians provided informed consent on behalf of their children. Each child was tested individually by an experimenter. Experimental procedures were approved by the local institutional review board (IRB). All participants received a small toy at the end of the study.

Procedure and Tasks

To test whether children individuate by spatial or featural cues, each child completed a forced choice object individuation task. On each trial of this task, children were shown two displays, presented simultaneously, side-by-side (22.7 cm × 22.7 cm; see Figure 1). One display (the spatial display) always contained identical objects with spatial separation (1.5 cm of spatial separation; see Figure 1A). The other display (the feature display) always contained featurally different objects without spatial separation. In the spatial display, the spatial information, but not the featural differences, indicate two separate objects. By contrast, in the feature display, featural differences (i.e., different colors or shapes), but not spatial separation, could indicate two separate objects. The order of presentation was counterbalanced across trials. Objects in each display were comprised of geometric shapes (5 cm × 5 cm) presented on a background of a picnic table with green foliage (downloaded from the internet; see Figure 1). The background provided an ecologically valid setting for the objects that reflected realistic environments in which children normally encounter objects.

The individuation task was comprised of two conditions, the choose *two* condition and the choose *one* condition. In the choose *two* condition, children were instructed to indicate which of the displays showed *two* objects. This condition indicates which cue—spatial or featural—children weight more when individuating objects. Choosing the spatial display indicates individuation by spatial cues, whereas choosing the feature display indicates individuation by featural cues (i.e., color or shape). In the choose *one* condition, children were instructed to indicate which of the displays showed *one* object. Here, choosing the feature display would indicate individuation by spatial cues, whereas choosing the spatial display would indicate individuation by features. If children select the display without spatial separation (the feature display) as indicating one object, this suggests high weighting of spatial cues. Selection of the spatial displays, in contrast, suggests high weighting of features because the contrasting features in the feature displays were seen as a stronger indicator of two objects than even the spatial separation in the spatial display. The use of the choose *one* condition, in addition to the choose *two* condition, verified that children did not select a display type based on a superficial preference for spatial or featural displays.

To keep children engaged, they were told stories about characters wanting exactly *one* (in the choose *one* condition) or *two* (in the choose *two* condition) objects. More specifically, in the choose *two* condition children were shown a picture of two mice and told: “This is Cheesy and this is Whiskers. Cheesy and Whiskers are going outside to play with some toys. They like to play together, but they don’t share toys. So we need two toys for Cheesy and Whiskers. Not one toy. We need two toys for Cheesy and Whiskers to play with. I’m going to show you some pictures with toys. You should tap the picture that has two toys for Cheesy and Whiskers. Tap the picture with two toys for Cheesy and Whiskers as fast as you can.” In the choose *one* condition children were shown a picture of one mouse and told: “This is Grumpy. Grumpy is going outside to play with his toy. Grumpy likes to play, but he only plays with one toy and he doesn’t share toys. So we need one toy for Grumpy. Not two toys. We need one toy for Grumpy to play with. I’m going to show you some pictures with toys. You should tap the picture that has one toy for Grumpy to play with. Tap with picture with one toy for Grumpy as fast as you can.” These specific instructions were used to ensure that children were selecting one or two things numerically, rather than by object identity. This was important because two objects could be interpreted as one kind of thing unless it was clear that number, not kind, was important to the task. Each child participated in both conditions (order counterbalanced; 24 trials per condition; total 48).

The object individuation task was created using a custom built Visual Basic program (Microsoft) and administered on a Dell PC equipped with a touch-screen (79 cm × 47 cm screen). Children were seated approximately 35 cm from the screen, and they responded by touching the display with their finger. Children's responses to each trial were recorded, as were their response times (RTs). To increase the reliability of children's RTs, they were instructed to place their hands on two foam handprints positioned 20 cm from the screen prior to the start of every trial. This procedure ensured that children were always responding from the same position. As it is unusual to measure reliable RTs in children of this age group, we included this procedure and analyzed these data for exploratory purposes.

At the beginning of the study, prior to the object individuation task, children were administered an abridged version of the 'give-a-number' task to ensure that children were familiar with the concept of 'one' and 'two,' (Wynn, 1990). Here, children were asked to hand the experimenter first one coin, then two coins, from a basket of coins. This ensured that every child was able to understand the task instructions. Next, to familiarize children with the touchscreen response procedure, children played a short game in which they were instructed to place their hands on the foam handprints and then 'catch a frog' that appeared on the screen by tapping it with their finger. After the familiarization task, children began the first condition block, either the choose *one* or choose *two* condition, followed by the remaining condition as the second block. As in the familiarization task, each trial began when the child's hands were on the handprints and the experimenter initiated each trial. To break up the blocks, and to ensure that children could robustly quantify one and two, the give-a-number task was repeated between the first and second conditions. Finally, at the end of the session, each child completed the Woodcock Johnson Picture Vocabulary test (Woodcock & McGrew, 2001). The purpose of this test was to assess children's vocabulary, which served in the current experiment as a control for general intelligence.

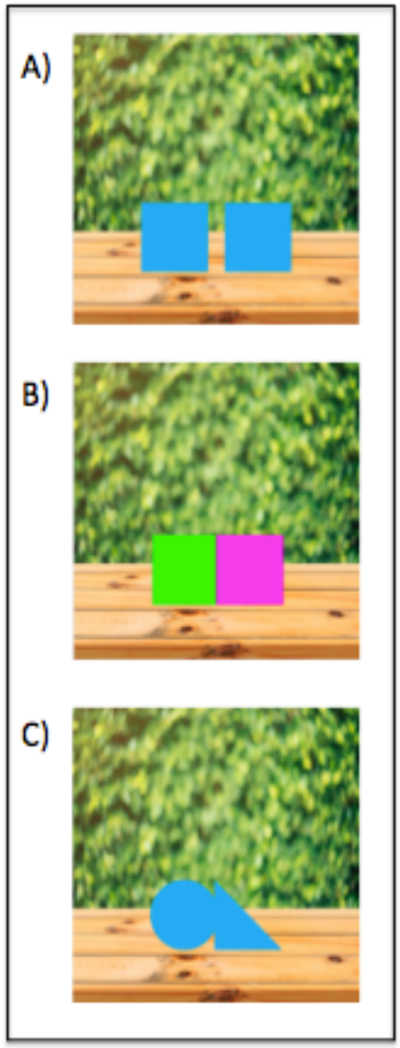

Figure 1. The three display types used in the forced choice object individuation task. A) An example of the spatial display*,* in which objects were presented with spatial separation, but identical features. B) An example of a feature display (color trial), in which objects were presented in adjacent positions but with different colors. C) Another example of a feature display (shape trial), in which objects were presented in adjacent positions but with different shapes. In the choose *two* condition, choosing the spatial display would indicate greater weighting of spatial cues for individuation. In the choose *one* condition, choosing the featural display would indicate greater weighting of spatial cues for individuation.

Results

Data Processing

To quantify whether children relied primarily on spatial or featural cues to individuate objects, we calculated an individuation score for each participant that represented the proportion of trials in which children based their individuation on spatial versus featural cues. For each trial across conditions, responses indicating individuation by spatial cues were coded as 1 (in the choose *two* condition, selecting the spatial display; in the choose *one* condition, selecting the featural display). Responses indicating individuation by featural cues were coded as 0 (in the choose *two* condition, selecting the featural display; in the choose *one* condition, selecting the spatial display). For each participant, this was averaged to create an individuation score. Higher individuation scores (greater than 0.5) would indicate that the child individuated primarily by spatial separation, whereas lower individuation scores (less than 0.5) would indicate that the child individuated primarily by features.

Three children were excluded from the analysis for failing the "give-a-number" task and one child was excluded for not finishing the study.

Main Results

To test whether individuation scores varied as a function of condition or feature type, we conducted a 2 × 2 repeated measures ANOVA with feature type (shape and color) and condition (choose *two* and choose *one* condition) as the within-subject factors, and sex and condition order as the between-subjects factors. This analysis revealed a significant main effect of feature type, such that the individuation scores for both conditions were higher when spatial cues were pitted against shape rather than color, $F(1,29) = 8.05$, $p = 0.008$, $\eta^2 = 0.217$. There was no main effect of condition, nor any interactions ($ps > 0.328$). Parallel analyses with RTs as the dependent variable revealed no significant main effects or interactions ($ps > 0.065$).

To examine whether children individuated the objects by spatial or featural cues in each condition, four one-sample t-tests were conducted to test whether children's individuation scores differed from the chance level of 0.50. This analysis revealed that, in the choose *one* condition, children's individuation scores were significantly above chance when the featural cue was shape, $t(32) = 4.348$, $p < 0.001$, or color, $t(32) = 3.029$, $p = 0.005$. In the choose *two* condition, children's individuation scores were significantly above chance when the featural cue was shape, $t(32) = 3.807$, $p = 0.001$, but not color, $t(32) = 1.245$, $p = 0.222$. Thus, overall, children weighted spatial cues more heavily than the featural cues when individuating objects.

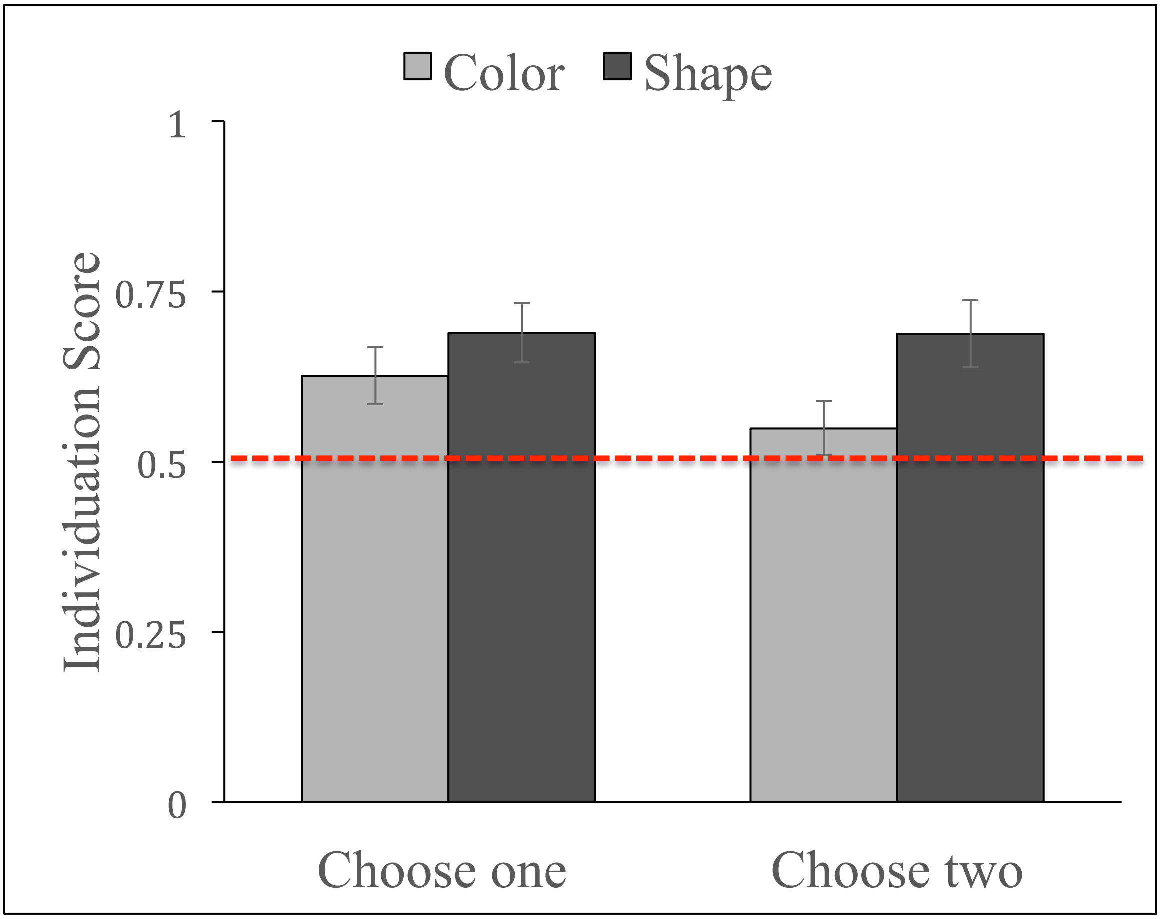

Figure 2. Children's individuation scores as a function of condition for the different feature types. In the choose one condition, children individuated by spatial cues across both feature types. In the choose two condition, children individuated by spatial cues when the feature type was shape, but when the feature cue type was color, individuation scores were not significantly above chance. The red dotted line indicates chance performance. The error bars show standard error of the mean.

Finally, to better understand the main effect of feature type, we conducted correlations for each feature type with children's age and vocabulary scores. This analysis revealed that age was significantly correlated with individuation scores when the feature type was color, $r(31) = 0.499$, $p = 0.003$, and marginally correlated when the feature type was shape, $r(31) = 0.340$, $p = 0.053$, suggesting that individuation by spatial cues in this task increased with age. There was no correlation between vocabulary scores and individuation scores for color or shape ($ps > 0.313$), suggesting that individuation performance was unrelated to vocabulary and, thus, likely unrelated to general intelligence.

Given the correlations between feature type and age, we further explored these relations by examining younger and older children's (median split = 4.00 years) individuation scores for color and shape. One sample t-tests revealed that children younger than 4 years individuated by spatial cues significantly above chance when the paired feature was shape, $t(16) = 3.039$, $p = 0.008$, but not color, $t(16) = 0.917$, $p = 0.373$. By contrast, children older than 4 years individuated by spatial cues significantly above chance regardless of whether the paired feature was shape, $t(15) = 4.109$, $p = 0.001$ or color, $t(15) = 2.923$, $p = 0.01$.

Discussion

Prior research revealed a developmental shift in how children weight visual information on object perception tasks, with greater weighting of spatial cues in infancy, and greater weighting of featural cues in preschool age (Ayzenberg, Nag, & Lourenco, 2017; Huan, Call, Janzen, & Levinson, 2006). One possible explanation for this shift is language acquisition (Xu & Carey, 1996). However, nonhuman primates' ability to individuate by features casts doubt on this explanation (Uller, Carey, Hauser, & Xu, 1997). Thus, we tested an alternate explanation based on components of object perception, object individuation and object identification. The current study tested the possibility that the specific object task children engage determines their cue weighting. Preschoolers have been shown to weight featural cues above spatial cues (Ayzenberg, Nag, & Lourenco, 2017; Huan, Call, Janzen, & Levinson, 2006). However, it is possible that their greater featural weighting reflects the task of object identification, unlike infants whose greater weighting of spatial cues may reflect the task of object individuation (Leslie, Xu, Tremoulet, & Scholl, 1998). We hypothesized that, if spatial cues are more reliable than features for object individuation, then preschoolers should weight spatial cues above features when instructed to individuate objects. To test this hypothesis, we designed an object individuation task in which preschoolers had to segment items into individual objects using spatial or featural cues, for which object quantity, but not identity, was relevant. We found that, overall, preschoolers weighted spatial cues above features to individuate objects. This finding suggests that the object perception task in which children engage impacts cue weighting, shedding light on the perceptual mechanisms that may drive cue weighting across development.

This study's main finding that preschoolers weighted spatial cues above features to individuate objects raises the question of what makes spatial cues so reliable for object individuation. Five-month old infants' sensitivity to changes in object number (i.e., Wynn, 1992; Simon, Hespos, & Rochat, 1995) suggests that they are capable of individuating objects from a young age, and they do so primarily by spatial cues (Leslie, Xu, Tremoulet, & Scholl, 1998). Infants individuate by spatial cues before developing the ability to individuate by features (Needham & Kaufman, 1997; Xu & Carey, 1996), and even when infants are capable of individuating by features, they continue to rely primarily on spatial cues (Needham & Baillargeon, 1997a; Needham & Kaufman, 1997). Likewise, despite the availability of both spatial and featural cues, preschoolers in this study primarily relied on spatial cues to individuate objects. Spatial cues may be especially useful for object individuation because spatial cues clearly delineate object boundaries to determine where an object begins and where it ends (Needham & Kaufman, 1997). Object boundaries play an important role in object individuation because they clearly delineate an object from its background (Vecera & Farah, 1997). In contrast to spatial cues, features may be less reliable for establishing object boundaries, particularly for infants who are just learning about objects because features often provide ambiguous boundaries (Needham, 2004; Needham & Kaufman, 1997). Individuation by spatial cues may arise earlier in development than individuation by features because infants learn that spatial cues are reliable for delineating object boundaries before they learn that features can also establish object boundaries, though less reliably. Theories of object perception also provide a framework for why spatial cues are so reliable for object individuation. Such theories purport that object individuation establishes object representations, or basic concepts of objects, by their spatial locations (Kahneman, Treisman, & Gibbs, 1992; Leslie, Xu, Tremoulet, & Scholl, 1998). Such initial object representations are argued to be devoid of identity information. For instance, Kahneman, Treisman, and Gibbs (1992) described object representations as 'object files' that only gained featural associations after object individuation took place via distinct spatial locations.

The present study also lends support to the notion that children's object perception undergoes development (Smith, Jones, & Landau, 1996). Notably, 5-month-old infants are sensitive to changes in object number but not object identity (Simon, Hespos, & Rochat, 1995). This suggests that the ability to individuate objects may develop before the ability to identify objects (Leslie, Xu, Tremoulet, & Scholl, 1998). Earlier development of object individuation than object identification supports the possibility that infants may place greater weight on spatial cues because, early in life, the primary goal of object perception is individuation, whereas 3- and

4-year-olds may place greater weight on featural cues because the goal for these children has shifted to object identification.

In addition to showing that preschoolers in the present study weighted spatial cues more heavily than both types of featural cues when engaging in object individuation, this study revealed that when color and shape were pitted against spatial cues, preschoolers were more likely to individuate by color than by shape. This finding suggests that color cues generated more conflict with spatial cues during the object individuation task. One possible explanation for this effect is that color offered a clearer indication of object boundaries than shape. As described above, spatial separation reliably provides unambiguous object boundaries. However, for the objects used in the present study, color cues may have served a similar role to spatial cues in indicating object boundaries.

Unexpectedly, this study also showed that spatial cue weighting in object individuation increased with age, particularly when the spatial cues were pitted against color. Given that infants robustly weight spatial cues above features in object individuation (Leslie, Xu, Tremoulet, & Scholl, 1998; Needham & Kaufman, 1997; Xu & Carey, 1996), one possible explanation for this effect may be the difficulty of the individuation task. The task may have been difficult for younger children because it presented an ambiguous situation in which both displays could be interpreted as showing two objects. It may have been easier for older children than younger children to understand that they should pick the display that most strongly showed two objects, as opposed to simply selecting a display that *could* show two objects. Additionally, this type of conflict may be more likely to come up in the choose *two* condition because the color display could suggest either one or two objects, whereas spatial displays can only reliably suggest two objects.

The present study is the first to our knowledge to test preschoolers in an object individuation task, presenting novel avenues for future research. As this study suggested that the specific task of object perception determines children's cue weighting, future research could replicate this study and also include an explicit object identification task. The prediction could be that whereas object individuation resulted in greater spatial weighting, object identification would result in greater featural weighting. This would further illuminate the importance of features in object identification as well as the perceptual mechanisms driving the shift in object property cue weighting.

Overall, this study revealed greater weighting of spatial cues for object individuation when pitted against featural cues. The present study was an especially strong test of the role of spatial cues in object individuation because, despite a general tendency for greater featural weighting at this age (Ayzenberg, Nag, & Lourenco, 2017), preschoolers reversed their cue weighting and weighted spatial cues above features in our task. This study shows that the perceptual task impacts children's cue weighting, supporting the possibility that the developmental shift in object cue weighting from greater spatial weighting in infancy to greater featural weighting in preschool age reflects the development of children's object perception abilities. Specifically, there may be a developmental shift from primary engagement in object individuation during infancy to primary engagement in object identification during the preschool years.

Appendix

Pilot Study with Verbal Interference

I conducted a pilot study using verbal interference to test the possibility that language might account for children's shift in cue weighting. As described below, I found no effect of verbal interference and this initial work helped to develop the alternative hypothesis related to individuation versus identification tested in the present study.

In this pilot study, I tested children (3- and 4-year-olds; *n* = 21) and adults (*n* = 21). This study was motivated by the following prediction: if language acquisition accounts for children's shift from greater spatial weighting in infancy to greater featural weighting in early childhood, then interfering with children's and adults' language processing during an undirected cue weighting task should cause them to revert to weighting spatial cues over features (cf. Hermer-Vasquez, Spelke, & Katsnelson, 1999; Winawer et al., 2007). Children and adults performed six blocks of an undirected cue weighting task that evaluated their weighting of spatial and featural cues both independently, as well as when placed in conflict such that children had to choose between cues (Ayzenberg, Nag, & Lourenco, 2017). For half of the blocks, participants performed the cue weighting task while simultaneously performing a verbal shadowing interference task in which they had to continuously repeat a list of words (verbal shadowing based on the protocol of Hermer, Vasquez, Spelke, & Katsnelson, 1999). We predicted that when there was no verbal interference, children and adults would weight the features more than the spatial cues, as in Ayzenberg and colleagues (2017). By contrast, we predicted that when there was verbal interference, children and adults would weight the spatial cues more than the features. However, we found no main effect of verbal interference on cue weighting, either for children or adults. Across verbal interference and non-verbal interference blocks, both children and adults weighted featural cues above spatial cues. This presents no evidence that language drives the developmental shift in cue weighting. Indeed, nonhuman primates' capacity to use features suggests that there may be an alternate explanation for children's shift in cue weighting (Cheries, Newman, Santos, & Scholl, 2006; Uller, Carey, Hauser, & Xu, 1997).

Pilot Study with Adult Participants

I also conducted pilot work with adult participants to determine whether a task could be designed to show faster and more accurate object individuation and object identification by spatial and featural cues, respectively. As described below, I found no effect of cue type on participants' speed and accuracy responses. This initial work also helped to develop the paradigm used in the present study.

Undergraduate participants from the Emory community (N = 46) viewed displays containing either two or three shapes (circles, squares, and triangles) of three colors (green, blue, and red) that were presented in adjacent positions or with spatial separation. In an object individuation task, participants were asked to indicate whether or not there were 'two' or 'three' objects in the displays. In an object identification task, participants indicated whether or not a particular shape (a square or triangle) was present in the displays. For both tasks, the same displays were used and accuracy and response times were measured. Spatial separation between objects and featural contrast were manipulated. If spatial cues support object individuation whereas featural cues support object identification, then in a speeded display, participants should be faster and more accurate when displays had spatial separation. By contrast, for identification, participants should be faster and more accurate when objects' features had greater contrast. However, we found no effects of spatial separation or featural contrast on participants' object individuation or object identification accuracy and response times. One possible explanation for this null effect is that, in adults, identification and individuation may occur at similar processing speeds and levels of accuracy (Grill-Specter & Kanwisher, 2005).

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