Relations among early object recognition skills: Objects and letters

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Abstract

Human visual object recognition is multifaceted, with several domains of expertise. Developmental relations between young children's letter recognition and their 3-dimensional object recognition abilities are implicated on several grounds but have received little research attention. Here, we ask how preschoolers' success in recognizing letters relates to their ability to recognize 3-dimensional objects from sparse shape information alone. A relation is predicted because perception of the spatial relations is critical in both domains. Seventy-three 2 ½- to 4-year-old children completed a Letter Recognition task, measuring the ability to identify a named letter among 3 letters with similar shapes, and a "Shape Caricature Recognition" task, measuring recognition of familiar objects from sparse, abstract information about their part shapes and the spatial relations among those parts. Children also completed a control "Shape Bias" task, in which success depends on recognition of overall object shape but not of relational structure. Children's success in letter recognition was positively related to their shape caricature recognition scores, but not to their shape bias scores. The results suggest that letter recognition builds upon developing skills in attending to and representing the relational structure of object shape, and that these skills are common to both 2-dimensional and 3-dimensional object perception.

Keywords

shape caricatures; letter recognition; object recognition

Letter recognition is studied both in the context of reading skill and as a subdomain of visual object recognition. There have been a large number of studies of young children's letter recognition skills from the perspective of reading readiness (e.g., Foulin, 2005; Katz & Frost, 1992; Stage, Sheppard, Davidson, & Browning, 2001) and research in this field has demonstrated the importance of letter detection and discrimination to reading skill for both beginning and advanced readers (e.g., Bolger, Borgwaldt, & Jakab, 2009; Reitsma, 1978; Rapp & Caramazza, 1989; Schoonbaert & Grainger, 2004). Research on letter recognition as a form of visual object recognition has found that developing expertise in letter recognition creates cortical visual regions specialized for letters (Cohen, Dehaene, Naccache, Lehericy, Dehaene-Lambertz et al., 2000; James & Atwood, 2009; James & Gauthier, 2006; James, James, Jobard, Wong, & Gauthier, 2005; McCandliss, et al. 2003). However, despite these advances, letter recognition has not been studied in relation to visual recognition of other kinds of objects.

Three observations suggest the value of considering the development of letter recognition skills in the context of more general developmental trends in visual object recognition. First, as Gibson and her colleagues suggested long ago (Gibson, Gibson, Pick, & Osser, 1962; see also Gibson, 1969), children's early experience with object naming and categorization – and the perceptual skills that such learning engenders – are likely to set the stage, for good or ill, for children's learning of letters and letter names. Second, recent research on children's confusions among letters (e.g., Treiman, Kessler, & Pollo, 2006) indicates that most errors in letter recognition reflect confusions between letters with similar shapes, not letters with similar sounds, underscoring the importance to letter recognition of how children represent object shape. Third, recent findings concerning developmental changes in the representation of 3-dimensional object shape have identified one aspect of general visual object representation that may be particularly critical to letter discrimination and recognition. The central purpose of the experiment reported here is to examine whether there is, as predicted, a relation between preschool children's representations of the shapes of common objects and their ability to discriminate letters.

Relational structure in object recognition

The potentially relevant aspect of object recognition concerns how children represent the 3-dimensional shapes of common objects, and derives from Biederman's (1987; Hummel & Biederman, 1992) Recognition-By-Components account of visual object recognition. By this account, humans form internal representations that are sparse geometric models of 3-dimensional object shapes built from a set of primitive volumes called "geons." These representations capture the whole object's geometric structure independent of viewing perspective and enable the recognition of individually unique instances of common categories – for example, the recognition of kitchen chairs, dining chairs, and over-stuffed armchairs as instances of a single category because all share the same foundational geometric structure.

A growing body of research has considered whether young children, like adults, recognize instances of early-learned count noun categories given sparse geometric models of the objects' shapes, like those in Figure 1, made from geon-like 3-dimensional volumes (e.g., Abecassis, Sera, Younas, & Schwade, 2001; Biederman, 1987; Mash, 2006; Smith, 2003). Particularly relevant to the present hypothesis are several studies (Jones & Smith, 2005; Pereira & Smith, 2009; Smith, 2003; Son, Smith, & Goldstone, 2008) that have examined 1 ½- to 3-year-old children's ability to recognize 3- dimensional shape caricatures as compared to rich and typical instances of common categories (see Figure 1). These experiments typically use a name-comprehension task in which children are shown three objects and asked to indicate the one that is named (e.g., "Show me the brush."). The major result is that children's ability to recognize shape caricatures emerges and then increases markedly during this age period (Pereira & Smith, 2009; Smith, 2003). Additional evidence indicates that recognition of shape caricatures is more strongly correlated with productive vocabulary size than with age (Pereira & Smith, 2009; Smith, 2003); that these representations support category generalizations (Son, Smith, & Goldstone, 2008); and that the ability to recognize such sparse geometric representations is delayed in children with language delay (Jones & Smith, 2005).

The further finding that specifically motivates the present hypothesis concerns a potentially important limitation on children's formation of these abstract representations of 3-dimensional object shape. There are two key component skills (Hummel, 2000; Hummel & Biederman, 1992; Marr & Nishihara, 1978): the abstraction of the major geometric parts of objects, and the representation of spatial relations among those parts. For example, a shape caricature representation of a chair requires that the perceiver represent a seat, a back, and some form of support for the seat as the major structural components – and not, for example, the padded arms on a living room chair, or the rockers on a rocking chair. The perceiver must also represent the spatial relations among these major parts –that is, the structural relations between the seat and the back and the supporting legs or pedestal. Our prior work suggests that young children are adept at recognizing the major component parts of objects and that the principle skill limiting children's shape caricature recognition is representing the relational structure formed by those parts (Augustine, Smith, & Jones, 2011). This component skill in visual object recognition would seem to be critical for letter recognition.

Hypothesis and rationale

Written letters are comprised of a very small set of features –lines and curves – that create different forms by the spatial arrangement of those features (Gibson et al., 1962; Treisman 1986; Lanthier et al., 2009; Grainger, 2008). For example, a "b" and a "p", or a "T" and an "L" differ only in the spatial relations among their common components. Thus, letter recognition could be viewed as a specialized form – in a specific domain, and with a specialized set of component elements – of the kind of visual representation system proposed by Biederman (1987; Biederman & Kalocsai, 1997). This hypothesis assumes that shape processing is a unified system (e.g., Hayward, 2003; Hummel, 2000; Marr & Nishihara, 1978; Peissig & Tarr, 2007; Vanrie, Willems & Wagemans, 2001) that has one developmental course for both 2-dimensional and 3- dimensional representations (e.g., Brincat & Connor, 2006; Miller, Nieder, Freedman & Wallis, 2003; Smith 2009). If this is so, then there could be a direct relation between young children's ability to recognize the abstract shapes of common objects and their readiness as they approach school to learn letters and letter names. Identifying such a relation could have practical as well as theoretical importance, since past research indicates that children's representation of the geometric structure of the shapes of common things is strongly related to and predicted by early language learning (Jones & Smith, 2005; Pereira & Smith, 2009; Smith, 2003), and another sizeable body of research suggests that children who have early delays in language learning often go on to have delays in learning to read (e.g., Bishop & Adams, 1990; Scarborough, 2009). Past research in small sample studies has shown that shape caricature recognition is typically evident in 2-year-olds. However, broader studies of this development – that involve a broader sample of the community – have not been conducted, and thus little is known about the range in these visual recognition skills. Accordingly, the experiment that follows examines the relation between shape caricature recognition and letter recognition in a broad sample of preschool-aged children.

Letter learning is a kind of object name learning task, and shape caricature recognition is known to be related to object name learning. Thus, it is possible that children's scores in the tasks measuring these two skills might be correlated because of their shared association with

individual children's ability to learn and generalize object names, and not because both skills require the representation and comparison of relational structures among object parts. To control for this possibility, we included a third task – the "shape bias" task – that measures object name learning based upon global object shape, and thus involves some of the same component skills as shape caricature recognition, but does not require the critical ability to represent the relational structure of parts within a whole.

The shape bias task was designed to measure children's generalization of a newly learned object name to new instances by shape (as opposed to color or texture or size: e.g., Imai, Gentner, & Uchida, 1994; Landau, Smith, & Jones, 1988; Samuelson & Smith, 2005; Soja, Carey, & Spelke, 1991). Critical to the present purpose, children in the task are presented with a novel made-up object with a very simple shape, told the novel name of that novel thing, and then asked in a forced choice procedure to indicate which of 3 test objects has the same name. Each test object matches the named exemplar in only one property, and the one that matches in shape –the choice that indicates attention to shape in this task – is an *exact* shape match. The two non-shape match choices do not share any structural components or shape similarity with standard. Thus, children do not need to abstract simpler parts from a more complex whole, or to represent the relations among those parts in order to succeed in the shape bias task. However, the task does require mapping a name to a thing, generalizing that name, and attending to shape rather than to color or texture.

Thus, the shape bias task is a particularly good comparison task for present purposes because attention to object shape in this task increases over the same developmental period in which children become increasingly better at recognizing shape caricatures (Colunga & Smith, 2005; Jones & Smith, 1993) and because success in the shape bias task, as in the shape caricature recognition task, is related to vocabulary development (Gershkoff-Stowe & Smith, 2004; Samuelson & Smith, 1999; Smith, 1999). Critically, although these facts suggest developmental relations between the shape bias and shape caricature recognition, the key prediction here is that there will be stronger developmental links between children's ability to recognize shape caricatures of common objects and their ability to discriminate among and recognize letters, than between the shape bias and letter recognition. Again, this prediction should hold if the representation of the relational structure among parts is a critical skill in both shape caricature recognition and letter recognition.

Method

Participants

Participants were 73 children (36 males and 37 females) between 2 ½ and 5 years of age (*Range* = 29 to 62 mos; M = 42.9 mos; SD = 7.42 mos). Twenty- three children were individually tested in preschools and 50 were tested in the laboratory. Care was taken to recruit children from the full socioeconomic range including from Title 1 preschools.

Procedures

Each participant completed the following tasks in the order in which they are listed:

1. Shape bias task

Stimuli: As in previous studies (e.g., Jones & Smith, 2002), children's shape bias was measured using a novel object name extension task. Three groups of nonsense objects were constructed in the lab. Each group had one category exemplar that was labeled with a nonsense name, and two sets of test items. There were 3 objects in each test set – each matching the exemplar only in shape, texture, or color. Again, the contrasting shapes in the choice set differed in global shape and also did not share individual components or relational structure with the exemplar object. All objects were between 20.5 and 146 cm^3 in volume. Figure 1 shows one set.

Procedure: Participants were presented with an exemplar object, told its name (e.g., "Look, this is a teeka."), and then given a short time to handle and examine it. After 15 seconds, the experimenter reclaimed the exemplar and placed three test objects in random order on the table about 25 cm apart in a line in front of the subject. With the exemplar object still in sight, the child was then asked for another member of the named category (e.g. "See my teeka? Can you give me another teeka?"). The child's first choice of a shape, color or texture match was recorded. Each of the exemplar objects was presented twice, each time with a different set of test objects, for a total of 6 unique trials.

2. Shape caricature recognition task—The MacArthur-Bates Communicative Development Inventory (CDI) - a widely used standardized measure of the first-learned words of children up to 30 months of age (Fenson, Reznick, Bates et al., 1993) – was consulted to identify 10 objects with names that are normatively known by at least 50% of 30 month olds – 'basket', 'butterfly', 'camera', 'couch', 'ice cream', 'kitten', 'lollipop', (builder's) 'nail', 'telephone', and 'truck'. Shape caricatures of these 10 familiar objects were constructed from Styrofoam and painted gray. Each caricature was formed by only 2 or 3 geometric shapes in proper spatial arrangement (see examples representing 'couch', 'ice cream', and 'basket' in Figure 2). All objects were between 74 and 196 cm^3 in volume. Three of the shape caricatures were presented on each trial and participants were asked for 1 object by name (e.g. "See all of these? Where's the ice cream? Can you give me the ice cream?"). The first object handed over by the child was scored. All children experienced the same 10 trials in different random orders, and the objects within each trial were ordered differently for different children.

3. Picture recognition task—This measure was included to determine which objects in the shape caricature task were familiar to each of the children in the sample, and thus detect any marked differences among children in their knowledge of common object names. Colored pictures of real world examples of the same 10 categories represented by the shape caricatures were printed on a white background, 12.7cm by 20.3 cm in area. On each of the ten trials, participants were shown 3 pictures and asked to point to the 1 object named by the experimenter.

4 Letter recognition task—Eleven sets of 3 letters with similar shapes were constructed from a larger list of "confusable letters" provided by Briggs and Hocevar (1975). These researchers created an index of confusability by first identifying 13 shape features of letters

of the Roman alphabet, then determining the subset of features composing each letter. This made it possible to give any pair of letters a "confusability score" by determining the percentage of their total features that were shared. For example, "E" and "F" both have 3 features ("horizontal top," "horizontal center," and "single vertical") in common, and E also has a fourth feature ("horizontal bottom"). The confusability score for this pair is therefore 6/7 or 86%.

On each letter recognition trial, participants were presented with 3 letters and were asked to point to the letter named by the experimenter (e.g., "See these letters? Can you point to the 'E'?). Stimuli were the 26 letters of the alphabet in upper case (because these are learned before lower case letters; Worden & Boettcher, 1990) each printed in dark blue on a white index card at a height of 6 cm. Table 1 shows the target letter and the 2 distracter letters for each of the 11 trials in this task, and the confusability scores of each target/distracter and distracter/distracter pair in each 3 letter set.

Results

Children's mean scores (with standard deviations) in the 4 tasks are provided in Table 2. All mean scores are reported as mean proportions correct. On average, children in this preschool-aged sample performed at levels well above chance (i.e., above 0.33 correct) in the all of the tasks (t (72) for all 4 means > 9.74, p<.001). Picture Recognition scores were very high for most children – 62 of the 73 children (85%) correctly identified 80-100% of the pictures. The very high mean score and restricted range in this measure assured that children were familiar with the common object categories represented by the shape caricatures. The same characteristics made Picture Recognition scores unsuitable for correlational analyses. However, there were large individual differences among scores on the other 3 tasks.

This finding of large individual differences in the Shape-Bias and Shape- Caricature tasks in this age range in noteworthy in and of itself. Because preschool children differ widely in how much formal and informal training with the alphabet, it is perhaps not surprising that performance in the letter recognition task – which was made more challenging by embedding target letters among other letters with similar shapes – ranged from perfect to quite poor. However, performance in the Shape Caricature and Shape Bias tasks also reflected marked individual differences despite the fact that a majority of children score well on these tasks when they are 1 to 2 years younger than those in the present sample (e.g., Smith, 2003; Smith, Jones, Gershkoff-Stowe & Samuelson, 2002). If these early skills involving object shape provide a foundation for later skills in other domains, then the individual differences observed here could have broad implications for cognitive development, a point we consider in the in the general discussion.

However, the primary empirical question was whether success in letter recognition would be specifically related to success in shape caricature recognition but not to success in the shape bias task. By hypothesis, it is only in the first two tasks that success depends on representations of the relational structures among object parts. Table 3 shows the Pearson correlations among Age, Letter Recognition, Shape Caricature Recognition, and Shape Bias

scores. Children's ages did not predict their performance on any of the tasks. Instead, as predicted, children's Letter Recognition scores were strongly correlated with their performance in the Shape Caricature Recognition task (t (71) = 6.16, p<.001) and not at all with performance in the shape bias task (t (71) = - 0.14, p = 0.24). Thus, although both the Shape Caricature Recognition task and the Shape Bias task involved mapping names to objects and shapes, only the Shape Caricature task, which requires a sparse representation of shape based on relational structure, was related to emerging letter recognition skills.

In line with recent findings by Yee, Jones, & Smith (2012), and with the proposal that the Shape Bias and Shape Caricature Recognition tasks measure children's use of different aspects of shape in object recognition, the correlation between children's scores on the Shape Bias and Shape Caricature Recognition tasks was statistically significant ($t_{(71)}$ = 3.25, p<. 002) but only moderate in size. In short, the pattern of results is consistent with the proposal that children's developing letter recognition skills make use of general processes used in the visual recognition of 3-dimensional objects – in particular, the representation of the relations among object parts.

General Discussion

The results of the present study suggest that changes in object perception and representation occurring in early childhood – specifically, the emergence of the ability to perceive and represent the abstract global shape characteristics of objects – might be a non-obvious factor in children's later reading success. The emergence of the ability to recognize the shape caricatures of common objects is thought to be important to the subsequently rapid learning and generalization of object categories, and part of a developmental shift in object recognition away from reliance on representations of piecemeal features and towards representations of the abstract geometric structure of objects as component parts in specific spatial configurations ((Jones & Smith, 2005; Pereira & Smith, 2009; Smith, 2009).

Past work has suggested that representations of the geometric structure of common objects emerge at around 2 years of age (Smith, 2003) but continue to develop well into middle childhood (Mash, 2006). The present findings indicate that such representations, while early in many young children, are neither early nor robust in some older preschoolers; and that, critically, children who have difficulty in recognizing common objects from caricature representations also have difficulty in recognizing and discriminating letters – a special class of visual objects. By hypothesis, recognizing shape caricatures and recognizing letters both involve representations built by a generative process, in which elements from a finite set are selected and arranged in any of a much larger set of configurations (Biederman, 1987). The correlations observed in the present study support this hypothesis, suggesting that there is overlap in the processes supporting both 3-D object representation and letter recognition.

Correlations are, of course, a first step and do not allow for any firm conclusions about causality or the direction of dependency, and the present results cannot tell us whether the children who did poorly in both the letter recognition and shape caricature recognition tasks were at risk for reading difficulties. However, the present findings provide supporting evidence for such a connection. Since we know that many young children well before

learning about letters have the ability to recognize the shape caricatures of common objects, it seems likely that this early skill may support the typically later development of letter learning. If this is so, then the present findings may provide a bridge between early delays in language development and difficulties in learning to read. We know from past work that shape caricature recognition is strongly related to early vocabulary size (Pereira & Smith, 2009; Smith, 2003), and is delayed in children with language delays (Jones & Smith, 2005). We see in the present result a strong relation between recognition of shape caricatures and of letters, but no relation between shape learning in the shape bias task and letter recognition. This pattern suggests that letter learning depends on skill in representing, not just shapes, but the relational structure among object parts. If early object name learning helps builds these skills, as proposed by Doumas and Hummel (2010; see also, Smith & Jones, 2011), then children who are delayed in language learning, for whatever reason, may start learning letters without the necessary skills in visual shape processing. If limited skill in representing the relational structure of visual elements underlies difficulty in learning letters, then – given the predictive relationship between letter recognition and learning to read – we can expect that children who have difficulty in representing the relational structure of objects and letters will have difficulty in reading. Thus, these results suggest that the previously observed link between an early lag in vocabulary development and later risk for reading difficulties (e.g., Scarborough, 1998; 2009; Rescorla, 2002) may, at least in part, reflect some children's difficulties in perceiving and representing abstract object shapes.

The range in performances of children of different ages in the letter recognition task is perhaps not surprising, because letter learning is specialized learning to which preschool-aged children in different circumstances may have different exposure. However, the range of performances of children in the shape caricature and shape bias tasks might be viewed as unexpected, given that these abilities are usually apparent in children up to 2 years younger than some in the present sample. Much research in cognitive development is concerned with describing the typical or normative developmental pathway, and often does not look at what might be wide variations in ages of skill acquisition in the broader population. However, the present results remind us that these variations might be considerable and – because development uses one achieved skill to build the next – broadly consequential. In this connection, the results raise specific questions about possible different developmental trajectories in visual object recognition and object name learning. The rapid and robust character of adult object recognition, even in less than ideal conditions, appears to depend on a multi-faceted system. For example, adults clearly represent the sparse geometric structure linking the major parts of objects, and can recognize objects given just this kind of information (e.g., Biederman & Gerhardstein, 1993; Hummel & Biederman, 1992). However, computational approaches to object recognition as well as empirical evidence suggests that adults represent individual diagnostic features, such as dog eyes or car doors, and can use them to recognize partially occluded objects even when overall shape cannot be determined (see Schyns & Bonar, 2002; Ullman, 2007). One recent study indicates that younger children emphasize such diagnostic features in object recognition more than do older children (Pereira & Smith, 2009). This finding may be relevant to the fact that some children, older as well as younger, did not do well in the shape caricature recognition task, yet presumably were able to recognize familiar objects by some other means. Perhaps these

children were emphasizing the diagnostic feature route to recognition over the shape route. This alternative route, however, would not work as well for letter learning. It would be worthwhile to pursue this possibility, as it seems likely that an intervention to enhance children's perception of the geometric structure of objects could be easily designed and might have a real, positive effect on children's reading success.

Finally, our results may also be relevant to the issue of whether object recognition processes are different for and specific to particular classes of stimuli (e.g, faces, body parts, and environments: Kanwisher, 2006; 2-dimensional and 3-dimensional objects: Spelke, Lee & Izard, 2010) or whether diffuse representations of objects in different categories are recognized by the same computational mechanism (e.g., Konen & Kastner, 2006; Riesenhuber & Poggio, 2002). These are hotly debated issues in the adult literature, but the developmental routes to these adult states have not been considered. The present evidence suggests that recognition of letters and of other kinds of objects depends at least in part on common processes. However, it could be that there is commonality and interaction early in development among the processes involved in recognizing different classes of things, and that specialization emerges later. Nonetheless, the substantial link observed in this study between accurate perception of 2- dimensional letter shapes and 3-dimensional objects are consistent with results from imaging studies that are invoked in current discussions of the nature of visual object recognition mechanisms. More specifically, neuroimaging studies of both monkeys and human adults have documented a hierarchical processing sequence that is comparable for 2-dimensional and 3-dimensional objects (e.g., Brincat & Connor, 2006; Konen & Kastner, 2006). Our results suggest that preschool-aged children too process 2-dimensional and 3-dimensional stimuli by means of the same mechanism.

Most generally, the results argue the importance of developmental data to our ultimate understanding of the processes involved in adults' generally effortless representation and recognition of objects in a wide range of cognitive tasks, including reading; and the utility of such understanding to remediation during development of important problems in object perception.

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Figure 1.
Example test stimulus set for the Shape Bias task: top item is the novel category exemplar.
Test items match the exemplar in shape or texture or color.

Figure 2.
Example test stimulus set for the Shape Caricature Recognition task: common noun categories – here, "couch", "ice cream", and "basket" – are represented by 3-D objects consisting of 2 to 3 volumes in grey Styrofoam representing major object parts.

Table 1

Confusability scores (range is 0 to 1.0) reported by Briggs and Hocevar (1975) for the 11 target letters and similarly shaped distracters used in the Confusable Letter Recognition Task.

Target Letter	Distracter 1 (Confusability with Target)	Distracter 2 (Confusability with Target)	Confusability between the 2 Distracters
Q	O (.80)	C (.50)	.80
M	W (.50)	N (.80)	.80
P	B (.91)	R (.91)	.83
E	F (.86)	I (.40)	.50
G	S (.50)	C (.50)	.50
L	I (.67)	T (.67)	.67
Y	X (.67)	V (.50)	.50
K	V (.40)	W (.67)	.67
J	D (.40)	I (.67)	.50
H	A (.50)	F (.40)	.40
Z	B (.44)	T (.40)	.50

Table 2

Range, Means, and Standard Deviations of the measures taken on 73 preschool-aged children. All test values are proportions of trials correct. Reported t-tests compare mean proportions correct choices with chance =0.33.

	Age (mos)	Shape Caricature Recognition	Letter Recognition	Shape Bias	Picture Recognition
Range	29 – 62	0.30 –0.90	.09 – 1.0	0.0 – 1.0	0.30 – 1.0
Mean	42.9	0.80	0.67	0.69	0.90
Standard Deviation	7.43	0.18	0.30	0.27	0.16
t (72) = **p <**		23.84 .001	9.74 .001	11.68 .001	29.82 .001

Table 3

Pearson correlations among measures (N=73 children). Correlations in bold yielded significant *t* scores in 2-tailed tests.

	Age (mos)	Letter Recognition	Shape Caricature Recognition	Shape Bias
Letter Recognition	0.14			
Shape Caricature Recognition	0.14	**0.59**[**]		
Shape Bias	0.11	−0.04	**0.36**[*]	

[*]
p 0.001

[**]
p 0.001