Cognitive Development 26 (2011) 40–56

Contents lists available at ScienceDirect

Cognitive Development

Developmental differences in shape processing

Maria D. Sera*, Katherine Gordon Millett

Institute of Child Development, University of Minnesota, 51 East River Road, Minneapolis, MN 55455, United States

ARTICLE INFO

Keywords:
Categorization
Object recognition
Object identification
Shape similarity
Shape processing

ABSTRACT

Considerable evidence indicates that shape similarity plays a major role in object recognition, identification and categorization. However, little is known about shape processing and its development. Across four experiments, we addressed two related questions. First, what makes objects similar in shape? Second, how does the processing of shape similarity develop? We specifically asked whether children and adults determine shape similarity by using categories (e.g., straight vs. curved), as proposed by Biederman (1987), or whether they treat all shape variability uniformly, as proposed by Ullman (1998). Findings from Experiments 1 and 2 suggest that adults and 7-year-olds generally engage in a process in which they impose categories on shape variation and judge objects that fall within those categories as being similar in shape. Four-year-olds are far less likely to engage in such a process. Experiments 3 and 4 address whether 4-year-olds are more likely to treat shape similarity categorically (as older children and adults do) when the objects are given familiar names, functions, and internal properties. Naming did lead to more advanced treatment of shape similarity in some cases. Overall, these findings provide evidence of developmental differences in shape processing and suggest that knowledge of abstract properties of objects may affect the calculation of shape similarity.

A large part of our understanding of objects in the world is based on how we categorize them. Categories can be based on a variety of features (color, texture, size, shape or function), all of which have been shown to be important for object recognition and identification (Diesendruck & Bloom, 2003; Landau, Smith, & Jones, 1998; Lin & Murphy, 2001; Rogers & McClelland, 2004; Waxman &

* Corresponding author.
E-mail address: sera@umn.edu (M.D. Sera).

0885-2014/$ – see front matter
doi:10.1016/j.cogdev.2010.07.003

Namy, 1997). Research over the past 35 years has shown that shape is one of the most important of these features (Biederman, 1987; Clark, 1973; Cutzu & Edelman, 1996; Smith, 2005; Ullman, 1998). We seek to advance the understanding of shape processing by addressing these questions: (1) What makes objects appear similar in shape? (2) Does shape similarity processing develop, and, if so, how? The first question has received considerable attention from researchers who study object perception, recognition, identification, and classification in adult and machine vision (Biederman, 1987; Cutzu & Edelman, 1996; Gibson, 1966; Ullman, 1998), but research has so far yielded no satisfactory answer. The second question has received relatively little attention.

We begin by reviewing the issues and findings relevant to the first question – what makes objects similar in shape? Inherent to the problem of shape similarity is the problem of shape constancy. The problem of shape constancy is that as one looks at an object from a number of different angles, that object creates a number of different visual images on the retina. Although the object looks different from various vantage points, the viewer must disregard the variability across different views in order to identify it. Similarly, to determine whether two objects are similar in shape, one must attend to certain similarities while disregarding certain differences. Although humans and young infants seem to routinely solve the problems of shape constancy and shape similarity (Cook & Birch, 1984) the processes by which they do so are not well understood. This is largely because, while much work has been done to identify the underlying similarity metric in other areas of perception (e.g., speech and color), researchers have yet to identify one for shape similarity. Therefore, using the literature on the similar (and inherent) problem of shape constancy as a guide, we attempt to identify a shape similarity metric by examining how children and adults classify objects according to shape.

A solution to the shape constancy problem was first proposed by James Gibson (1966), who stated that when viewing an object from different angles we extract and only attend to the dimensional properties of the object that are invariant or view-independent. While Gibson's insight was an important first step toward understanding what kinds of variation the observer attends to or ignores, it does not account for the fact that the shape features of many objects do depend on viewpoint. For example, a round plate, when viewed from various angles, projects different ellipses on the retina. Thus, there does not seem to be view-independent information specifying a particular degree of curvature.

Consequently, solutions have been proposed in which the viewer does not extract invariant properties. According to one, the viewer "averages" shape information received from different viewpoints (Ullman, 1998). Such solutions are compatible with prototype models of categorization, in which all of an object's features are processed in a similar fashion. Biederman (1987) proposed a contrasting solution in which shape variations along certain dimensions (degree of curvature, for example) are grouped into categories such as "curved." This view is more compatible with classical views of categorization in which some kinds of variation are more important than others. Both the Ullman and Biederman accounts have addressed the problem of shape constancy, have been extended to the processes involved in object identification and shape similarity, and have received empirical support (Kayaert, Biederman, & Vogels, 2003). We summarize the two approaches next.

According to Ullman's (1996, 1998) account, every experienced view of an object plays an equal role in determining its "average" shape that is then used for recognition and identification. Thus, variability based on different viewpoints is attended to and added to the abstract shape representation. The categorization of an object into a class by shape similarity is determined by comparing it to a stored average of all previously experienced views of objects of different classes. For example, based on one's past experiences with bowls having edges of different degrees of curvature, one's shape representation of the category *bowl* would consist of the average of those degrees of curvature. The same process would lead to an abstract representation of the category *cup*. Then, on seeing a particular object, one would compare its curvature to the average curvature of the *bowl* and *cup* categories, and the object would be classified in the category to which its shape is most similar.

Biederman (1987) has taken a different approach. One does not attend to all of the variations in shape when viewing objects, instead, objects are classified in a dichotomous manner (e.g., as having curved or straight edges). The difference between two curved objects is called "metric," and the difference between a curved and a straight object is called "non-metric" or "dichotomous." Critical to this view is the idea that metric shape differences are irrelevant to object recognition and identification. We do not calculate the exact degree of curvature or the exact sizes of the angles of an object's edges