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Greater sensitivity to nonaccidental than metric shape properties in preschool children

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ABSTRACT

Nonaccidental properties (NAPs) are image properties that are invariant over orientation in depth and allow facile recognition of objects at varied orientations. NAPs are distinguished from metric properties (MPs) that generally vary continuously with changes in orientation in depth. While a number of studies have demonstrated greater sensitivity to NAPs in human adults, pigeons, and macaque IT cells, the few studies that investigated sensitivities in preschool children did not find significantly greater sensitivity to NAPs. However, these studies did not provide a principled measure of the physical image differences for the MP and NAP variations. We assessed sensitivity to NAP vs. MP differences in a nonmatch-to-sample task in which 14 preschool children were instructed to choose which of two shapes was different from a sample shape in a triangular display. Importantly, we scaled the shape differences so that MP and NAP differences were roughly equal (although the MP differences were slightly larger), using the Gabor-Jet model of V1 similarity (Lades & et al., 1993). Mean reaction times (RTs) for every child were shorter when the target shape differed from the sample in a NAP than an MP. The results suggest that preschoolers, like adults, are more sensitive to NAPs, which could explain their ability to rapidly learn new objects, even without observing them from every possible orientation.

1. Introduction

Children can quickly learn new objects, even when the objects are presented from a single static view (such as the animal pictures in a typical children's book). What accounts for this ability? When a 3-dimensional object is rotated in depth, its 2-dimensional projections on the retina can vary greatly. Biederman (1987) suggested that in order to achieve robust object recognition despite such image changes, certain shape properties that are view invariant might receive greater weight by the system involved in object recognition. Those view-invariant shape properties have been termed *nonaccidental properties* (NAPs) (Lowe, 1985), e.g., whether an edge is straight or curved or a pair of edges coterminate or not, and are distinguished from metric shape properties (MPs), whose 2-dimensional projections vary continuously as a function of rotation in depth, e.g. degree of curvature, degree of taper.

More generally, Amir, Biederman, and Hayworth (2011) noted that dimensions of shape can be regarded as extending from a *singular* or zero value (e.g., a straight contour with 0 curvature or parallel contours with a 0 angle of convergence) to an infinity of *non-singular* values (e.g., curves and non coterminating pairs of contours). With the exception of accidental viewpoints (as when a curve projects a straight line), as orientation in depth is varied, a singular value remains singular, and a non-singular value will vary but remains non-singular. The difference between singular and nonsingular values will always be nonaccidental but the difference between two nonsingular values will be metric. Lowe (1985) and Biederman (1987) noted that relying on nonaccidental properties can allow a vision system to represent the environment in a less view-dependent manner. Fig. 1 shows several examples of such changes along six different shape dimensions.

In line with Biederman's hypothesis, many studies of adult humans report a greater sensitivity to NAPs relative to MPs (Amir et al., 2012; Kukkonen et al., 1996; Wagemans et al., 2000), even in cultures not extensively exposed to modern artifacts (Biederman, Yue, & Davidoff, 2009). Differences in NAPs confer an enormous gain relative to differences in MPs in matching depth-rotated objects (e.g., Biederman & Bar, 1999; Biederman & Gerhardstein, 1993; Biederman, 2000). NAPs promote perceptual grouping (Feldman, 2007) and categorization (Abecassis et al., 2001) to a greater extent than MPs. Animal studies too, report

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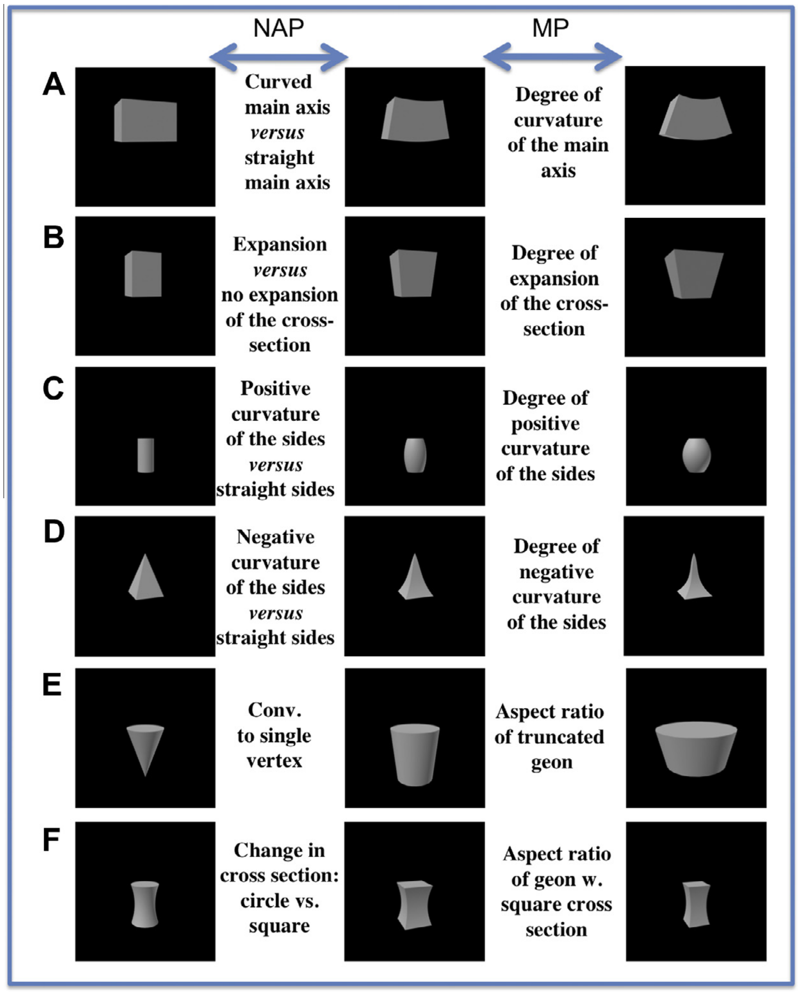

Fig. 1. Six sample sets of stimuli (from those used in the present experiment), exemplifying all the dimensions used in the experiment: (A) Main axis curvature, (B) Taper, (C) Positive curvature, (D) Negative curvature, (E) Convergence to a single vertex (vs. aspect ratio of truncated geon), (F) Cross section change (vs. aspect ratio of cross section) In (F), the nonaccidental change from a circular to a square cross section is not the same attribute as the metric change in aspect ratio of the cross section but the latter does provide a metric variation of the cross section. Modified from Fig. 2 in Amir, Biederman, and Hayworth (2012).

greater sensitivity to NAPs in pigeons (Lazareva, Wasserman, & Biederman, 2008) as well as single unit recordings in macaque inferotemporal cortex (Kayaert, Biederman, & Vogels, 2003; Vogels et al., 2001).

Only a handful of studies examined sensitivity to NAPs in younger humans, with somewhat mixed results. On the one hand, Kayaert and Wagemans (2010) reported that infants as young as 3 months are more sensitive to a NAP (convergence to vertex) compared to an MP (aspect ratio). In their study, infants viewed either a triangle or a trapezoid multiple times until they became habituated to the shape. Then the infants were presented, side-by-side, with a shape varying in aspect ratio from the stimulus they were habituated to, and one varying in convergence to vertex (i.e., if the habituated stimulus was a triangle it was a trapezoid, and vice versa). Infants were more likely to look at the shape that varied in convergence to vertex, presumably because they were adapted to (or "bored" with) the habituated shape, and the shape varying in convergence to vertex appeared to differ more from the habituated shape.

On the other hand, three studies of preschool children are sometimes taken as evidence that, unlike adults, preschoolers do not show greater sensitivity to NAPs. In 2011, Ons and Wagemans used a delayed match to sample task with 3–7 year olds. They showed that sensitivity to non-linear shape transformations (that produce changes in NAPs) relative to affine transformations (which preserve NAPs) increase with age. Abecassis et al. (2001) and Sera and Millett (2011) used novel physical objects to test categorization in children and adults. Children and adults were introduced to novel physical objects that were given a name (e.g. "Wug"). They then were presented with objects that differed either in MPs or NAPs from the original object. Adults, but not preschool children, were more likely to call the MP varied objects "Wug," than extend that name to the NAP varied objects. Similar results were obtained when, rather than naming the objects, children were asked which one of the varied shapes is "more like" the original one they have seen.

While these studies suggest children are less sensitive to NAPs relative to adults, they cannot be interpreted to suggest children are not more sensitive to NAPs than MPs. In order to compare relative sensitivities to any shape differences, one needs a principled measure of the relative magnitudes of the *physical* differences. Abecassis et al. (2001) did attempt a scaling by employing, for example, equal differences in curvature and eliciting judgments of similarity from adult observers. However, that geometrical differences produce equal psychological differences is an untested assumption. In general, two centuries of psychophysical scaling, e.g., Weber's and Fechner's Law, suggest that it is rare that geometrical and psychophysical measures are equivalent. If humans are more sensitive to differences in NAPs than MPs, subjective