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Delayed shape matching benefits from simplicity and symmetry

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ABSTRACT

The aim of this study was to evaluate the influence of complexity and symmetry on shape recognition, by measuring the recognition of unfamiliar shapes (created using Fourier Boundary Descriptors, FBDs) through a delayed matching task. Between complexity levels the shapes differed in the frequency of the FBDs and within complexity levels in their phase. Shapes were calibrated to be physically equally similar for the different complexity levels. Matching two sequentially presented shapes was slower and less accurate when complexity increased and for asymmetrical compared to symmetrical versions of the shapes. Thus, we show that simplicity in general and symmetry in particular enhance the short-term recognition of unfamiliar shapes.

1. Introduction

The goal of this research is to evaluate the influence that complexity and symmetry can have on human shape recognition. We do this using a delayed matching task, i.e., by measuring short-term recognition of previously unfamiliar shapes.

Complexity as a factor in visual perception research dates back to the Gestalt law of *Prägnanz*, which states that our perceptual experience of a visual scene will always be as 'good', i.e., simple, homogeneous, regular... as possible (Hochberg, 1957; Koffka, 1935). This relates to the most general principle of Gestalt psychology, the minimum principle, which states that the visual system strives for the simplest possible or 'minimal' perceptual organisation possible (e.g., Hatfield & Epstein, 1985). Since then, different authors have proposed a formal system to define the complexity of a perceptual organisation or perceived shape. Thus, authors designed ambiguous images (corresponding to multiple possible objects/scenes) and checked whether the favoured percept of their subjects corresponded with the simplest scene according to their model. For example, objects could be seen as either bi- or tri-dimensional (Attneave & Frost, 1969; Hochberg & McAlister, 1953), or tri-dimensional objects could be interpreted in different ways (Perkins, 1976). Similar methods were used to validate the Structural Information Theory or SIT (Leeuwenberg, 1969; Van der Helm & Leeuwenberg, 1996), probably the most-developed theoretical attempt to describe the 'cost' of a percept (Palmer, 1999). Among other operationalisations, Leeuwenberg and coworkers used pairs of shapes that could be seen as either overlapping or next to each other as in a mosaïc (Buffart, Leeuwenberg, & Restle, 1981; Van Lier, Van der Helm, & Leeuwenberg, 1994), overlapping line-drawings that could be segmented in different ways (Van Tuijl, 1980), and figure-ground assignments (Leeuwenberg & Buffart, 1984).

One logical hypothesis, following from these theories and experiments, would be that simplicity also has an influence on the perception of non-ambiguous shapes, and that it would ease the processing of these shapes, resulting in a better performance in visual tasks such as matching or recognition (Donderi, 2006). This is partly confirmed in the literature on mental rotation of two-dimensional shapes, where it seems that complexity can result in higher reaction times during the simultaneous visual comparison between (rotated) shapes, at least when using untrained shapes (Bethell-Fox & Shepard, 1988; Cooper & Podgorny, 1976; Folk & Luce, 1987; Hall & Friedman, 1994; Pellegrino, Doane, Fischer, & Alderton, 1991). In these studies, the shapes were calibrated to be equally similar within each complexity level, using similarity ratings from a different pool of subjects. This fits the purpose of this line of research, namely to find out how complexity interacts with the task of matching shapes that are rotated or differ in size, but it is less suited to study shape recognition, since shape recognition and similarity ratings correlate with each other and could both be influenced by complexity. Thus, by equalizing the simple and complex shapes according to similarity ratings, one might reduce or remove the effect that is to be measured.

Moreover, the exact nature of the task influences the effect of complexity. Larsen, McIlhagga, and Bundesen (1999) compared performance during such a simultaneous matching task with performance during a delayed matching task, using line patterns (i.e., non-closed polygons). The number of lines (correlating with

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the complexity of the pattern) clearly and significantly resulted in an increase in reaction times during the simultaneous matching, but only very small corresponding tendencies were observed during delayed matching. The authors suggested that the differences between tasks may be due to subjects encoding only subparts of the image for delayed matching, thus reducing the complexity of the template they use for the matching part, while matching a more complete image, if necessary in several steps, during simultaneous matching.

Older studies on the influence of complexity during delayed matching provided mixed results. Vanderplas and Garvin (1959) found greater accuracy (reaction times were not measured) when recognising simpler polygons, but Clark (1968), using the same kind of shapes, did not. The main difference between the studies concerns the similarity between the targets and their distractors, which was not controlled for. It is indeed a flaw that none of the studies equated the physical shape difference between targets and distractor shapes over complexity levels. The same can be said of the study of Mavrides and Brown (1969) who manipulated the redundancy in the shapes of random polygons, which can be seen as inversely correlated with complexity (Donderi, 2006). Their results were counterintuïtive, showing that the more redundant (i.e., the less complex) shapes were more difficult to remember. But redundancy also diminishes information content and results in the less complex shapes being more similar to one another, thus biasing any test for the influence of complexity (Donderi, 2006).

We studied visual short-term memory using a delayed matching task with short presentation durations and a stimulus interval of half a second. Our first stimulus set, used in Experiments 1 and 2, is presented in Fig. 1A and B. There are three levels of complexity (the three columns defining the vertical panels in Fig. 1A and B), each containing five shape pairs that constitute the 'different' trials in our delayed matching task (the rows in each panel in Fig. 1A and B). We used curved and straight versions of all shapes (Fig. 1A vs. Fig. 1B). We can thus measure whether the complexity group to which a pair belongs influences the sensitivity of the subjects to the shape differences during a delayed matching task and this for both curved and straight shapes.

We manipulated complexity by increasing the frequency of the Fourier Boundary Descriptors (FBDs) that determine the boundaries of the shapes (see Section 2). This corresponds to increasing the number of concavities and convexities, an image property that correlates with complexity (e.g., Attneave, 1954; Chipman, 1977; Cutting & Garving, 1987; De Winter & Wagemans, 2006; Hatfield & Epstein, 1985; Leeuwenberg, 1969; Richards & Hoffman, 1985; Zusne, 1970).

The shapes within each level of complexity differed from each other in the phase of their FBDs. Manipulating shape like this has the advantage that the physical magnitude of the shape differences can be strictly calibrated (as it usually increases monotonically with increasing phase difference). Even more importantly, manipulating the phase of FBDs will not generate new, sometimes salient features (like very sharp angles, salient protrusions or indentations, subpatterns that can bear meaning), that are known to affect shape perception (e.g., De Winter & Wagemans, 2008). Especially this second advantage differentiates this paradigm from research with completely random polygons.

The stimulus pairs used in the 'different trials' are calibrated to be physically equally similar for the different complexity levels. The physical magnitude of the shape differences in our stimulus set was measured by computing the Euclidean distance between the grey-level values of the pixels of the images. We used the following formula: $((\sum_i^n (G_i^1 - G_i^2)^2)/n)^{1/2}$ with G^1 and G^2 the grey-levels for picture 1 and 2 and n the number of pixels. Sensitivity to a shape change can to a large extent be determined by the Euclidean distance between the shapes; that is why it is often used as a null hypothesis against which more specific perceptual hypotheses can be tested (e.g., Cutzu & Edelman, 1998; Grill-Spector et al., 1999; James, Humphrey, Gati, Menon, & Goodale, 2002; Kayaert, Biederman, Op de Beeck, & Vogels, 2005; Kayaert, Biederman, & Vogels, 2003, 2005; Op de Beeck, Wagemans, & Vogels, 2001, 2003; Vogels,

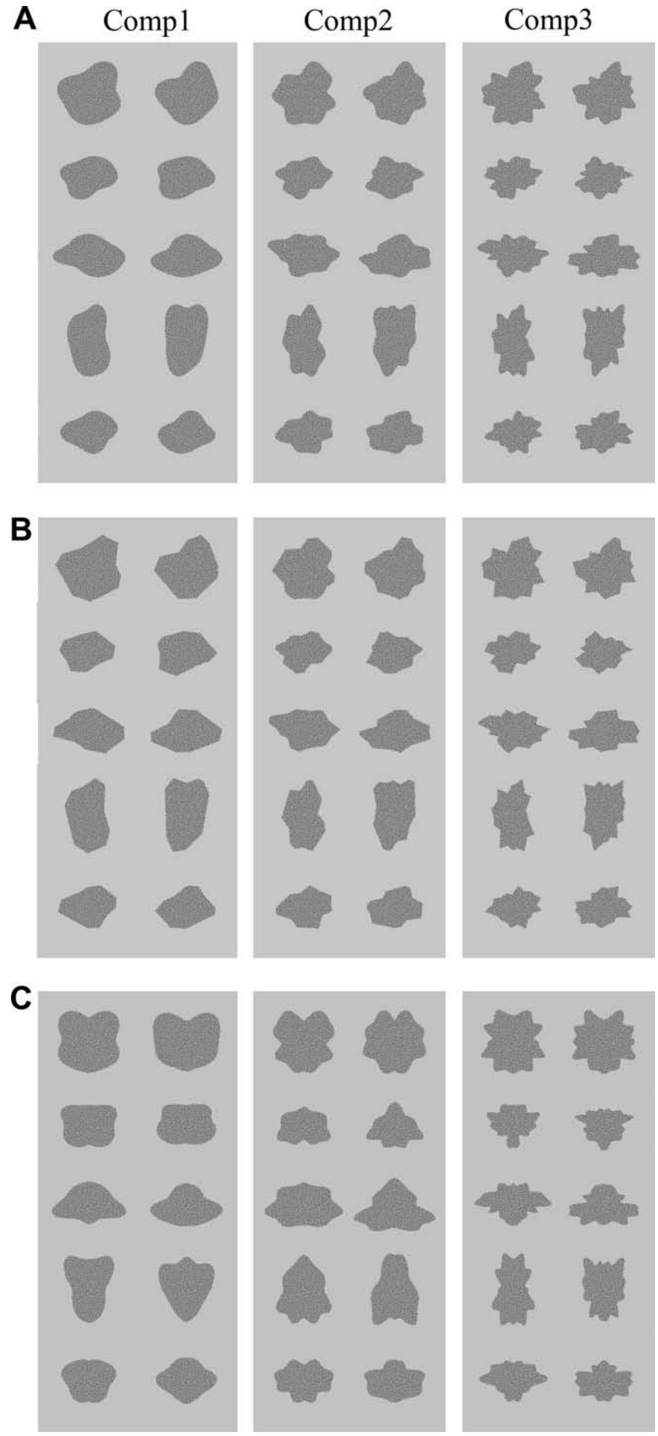

Fig. 1. Representation of the stimulus sets used in the first three experiments. The stimuli presented in Fig. 1A and B were used in Experiments 1 and 2. There are three levels of complexity (the three columns defining the vertical panels, labelled Comp1, Comp2 and Comp3, respectively, in ascending order of complexity), each containing five shape pairs per stimulus set (the rows in each panel). We used curved and straight versions of all shapes (A vs. B). C shows the symmetrical versions of the shapes; those were used in Experiment 3, together with the shapes in A.