Vision Research 72 (2012) 63–73

Contents lists available at SciVerse ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Pigeons show efficient visual search by category: Effects of typicality and practice

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ARTICLE INFO

Article history:
Received 1 March 2012
Received in revised form 27 July 2012
Available online 27 September 2012

Keywords:
Attention
Visual search
Category
Prototype effect
Automaticity
Pigeons

ABSTRACT

Three experiments investigated category search in pigeons, using an artificial category created by morphing of human faces. Four pigeons were trained to search for category members among nonmembers, with each target item consisting of an item-specific component and a common component diagnostic of the category. Experiment 1 found that search was more efficient with homogeneous than heterogeneous distractors. In Experiment 2, the pigeons successfully searched for target exemplars having novel item-specific components. Practice including these items enabled the pigeons to efficiently search for the highly familiar members. The efficient search transferred immediately to more typical novel exemplars in Experiment 3. With further practice, the pigeons eventually developed efficient search for individual less typical exemplars. Results are discussed in the context of visual search theories and automatic processing of individual exemplars.

1. Introduction

Humans and most nonhuman animals are often required to search for members of categories that are embedded within spatially distributed distractor objects in their natural environment. For a ground-feeding pigeon, for example, efficient searches for a variety of edible items in complex visual arrays are of great relevance to survival. Real-world searches almost always involve complex multiple objects that are not well specified by a single feature or a set of features.

Inefficiency in searching for either of two (or more) targets relative to a single target is known as dual-target cost. With humans, however, it has been shown that dual-target cost is likely to be diminished (i.e., search is more efficient) when a set of targets can be completely separated from a set of distractors with a single line in a stimulus space (i.e., linear separability). Most studies have used targets that are well defined by physical features, such as color and orientation (e.g., D'Zmura, 1991; Menneer et al., 2007), and very little research has examined concurrent visual searches for complex naturalistic items.

Wolfe et al. (2004) used categorical pictures of real objects (animal, fruit, tool, etc.) in search tasks in which the target is specified just prior to the appearance of the search display on each trial. Search was efficient when target identity was cued with a picture that exactly matched the target but the effectiveness of the cues diminished when the cues only specified the target category. Wolfe et al. argued that, although category cues produced little or no top-down guidance, more guidance could be seen with categories that have more obvious common features. Levin et al. (2001) addressed the role of categorical information, using pictures of objects in well-learned superordinate categories (*animal* and *artifact*). In a series of searches for a randomly selected animal target among a mixed set of artifact distractors and vice versa, they found an efficient search by category. Basic visual features, such as rectilinearity, that could distinguish these categories facilitated search for various exemplars of the complex categories.

More recently, Menneer, Cave, and Donnelly (2009) used X-ray images and demonstrated that simultaneous search for two different categories of weapons (guns and knives) among typical baggage objects was as efficient as search for only a single category and search performance improved with practice. The exact color and shape of various X-ray images varied within and across the categories, but all category items were distinguished by the color *blue* and thereby linearly separable from a variety of distractors characterized by the color *green*. Menneer et al. argued that, when target representations share features (in this case colors), the search can be guided by common components on the most informative dimension. In contrast, there was a cost for simultaneous search for the category of metal threats (the color *blue*) and the category of improvised explosive devices (the color *orange* or mixed coloring). In this case, the targets categories were not linearly separable from the distractors characterized by the color *green* and the cost did not diminish even with extensive practice.

Shiffrin and Schneider (1977) have claimed that, when a category is well-learned, due to much practice, then categorical

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http://dx.doi.org/10.1016/j.visres.2012.09.013

information will automatically guide search in the absence of controlled allocation of attentional resources. As a result of category learning, target detection is fast, automatic and effortless; it is parallel in nature and virtually unaffected by memory load. Logan (1988) proposed that representations of individual exemplars in long-term memory rather than representation of the category itself are responsible for the automatic processing. According to Logan's instance theory, some or all of the long-term memory representations of individual exemplars are retrieved by the onset of each search display and the activation of a given item in a display is determined by net similarities to the activated individual exemplars.

Automaticity of non-categorical individual items has been found in humans in experiments that manipulated the number of possible targets (i.e., the memory set size) or the number of display items (i.e., the display size), or both. Initially, reaction time increases with the number of items in either a memory set or a display, but after considerable practice, the search slope approaches zero (see Schneider and Shiffrin (1977) for a review). D. Blough (1979) and P. Blough (1984) used geometric forms or alphabetic letters for pigeons and found that memory set size up to six had no effect on the search by highly practiced pigeons. To account for such a finding, they proposed automatic processing of individual items. Vreven and P. Blough (1998) successfully demonstrated a shift from controlled to automatic processing with practice, in terms of decreasing run advantage during single-target trial sequences compared with search during mixed-target trial sequences.

The present study explores category search in pigeons. We created an artificial category by morphing of human faces. The morphing process is a two-step process, involving warping and averaging on a pixel-by-pixel basis (see Busey and Tunnicliff (1999) for more details). We do not know the exact physical properties of complex pictures created by morphing. So, we are unable to describe the specific physical features available for pigeons to discriminate the morphed images. However, pigeons perceive morphed faces as being similar to, but still discriminably different from, the originals from which they were created (Jitsumori, Shimada, & Inoue, 2006).

Artificial categories comprising of morphed faces have been employed in categorization studies with humans. Goldstone and colleagues (e.g., Goldstone, Steyvers, & Rogosky, 2003) used category exemplars consisted of a series of faces that were located along the left end or the right end of a continuum of morphed faces. Participants who learned to classify exemplars into the reference category (the category labeled "club members" consisted of exemplars lying on the left or right side of the continuum) and the nonreference category (the other category labeled "not club members") then showed better detection for the reference than nonreference exemplars among novel, category-unspecified, original faces (Corneille et al., 2006). This search asymmetry was explained by assuming that the reference category, but not the nonreference category, was organized around a prototype of the category. Unlike the studies of Goldstone and colleagues, we use a single category characterized by a single original face from which various exemplars are created via morphing transformations.

The target category was prepared individually for each pigeon. The upper part of Fig. 1 shows the category used for one of four pigeons in the present study. One face (Face P) arbitrarily selected from five faces without repetition among the pigeons was morphed with each of the remaining four faces (Faces A, B, C, and D, with the letters arbitrarily assigned to the four faces) to create the composite faces AP, BP, CP, and DP. We also created 50% morphs of the possible pairs of A, B, C, and D (AB, AC, AD, BC, BD, and CD) each of which was then morphed with P to create additional composite faces (ABP, ACP, ADP, BCP, BDP, and CDP). They were introduced to increase the net similarities among exemplars; for example, ABP is similar to AP and BP, and thereby ABP increases the net similarities.

The composite faces connected with broken lines in Fig. 1 have the same proportion (50%) of Face P. The 50%P faces[1] were used as the targets during baseline training. The targets are therefore characterized by the common component P. Faces A–D, as well as AB–CD, were used to create the individual exemplars; hence they are referred to as "item-specific" components. The item-specific component faces could be poor members of the category due to similarity to some, but not all, exemplars used for training (e.g., A is a part of AP, ABP, ACP, and ADP). The faces were from a single face class (i.e., Japanese male student), which allows us to examine effects of the common and item-specific components on search performance, by eliminating specific differences between the faces of these different types of component. The distractors (the lower part of Fig. 1) were category-unspecified nonmembers that differed in terms of ethnic affiliation, sex, and age.

Any of the item-specific components is not necessary for membership of the category; not all exemplars have A (or B, C, D) and exemplars containing novel item-specific components could be members of the category characterized by P. The category permits membership to a large, potentially infinite, number of instances created by morphing the common component with a wide variety of item-specific components. We define the original face, which is the basis for morphing transformations, as the prototype of the category; this is Face P. An average of category exemplars varies depending on item-specific components and proportion of the common component, while the common component face defined as the prototype is invariant.

Features of the common component P change as a result of morphing, with the changes dependent on the item-specific component into which it is blended. Resulted features are correlated, but not perfectly, within the category. Feature correlation increases as a function of the proportion of the common component. When it increases, composite faces become more similar to one another and to P (i.e., centrally located members of the category). When it decreases, composite faces become less similar to one another and to P, and instead become more similar to the corresponding item-specific component face (i.e., peripherally located members of the category). Features of composite faces are *not* perfectly correlated within the category like as most natural categories, in contrast to classic categories in which defining features (a conjunction of necessary and sufficient features) are perfectly correlated within categories and thereby all members of a category have equal status. For the artificial category used in the present study, the common component features are the features that create resemblance among exemplars. The item-specific component features are the features that create variability among these exemplars. Physical features of a face created by morphing differ from those of the common component and item-specific component, so that a 50%P face is not a face that has 50% features of the common component and 50% features of the item-specific component.

Jitsumori, Ohkita, and Ushitani (Experiment 1, 2011) used two categories created similarly to the category used in the present study. Pigeons were trained to respond to exemplars of one category (the positive category) and not to respond to exemplars of the other category (the negative category) in a go/no-go discrimination procedure. Each exemplar was a 50% morph of a common

[1] The pigeon's retina contains more than three morphologically distinguishable cones bearing oil droplets of different color. A reviewer pointed out that, when morphing color pictures, colors are mixed, thereby creating hues that can look to pigeons more similar/dissimilar to either of the two source pictures. What is critical for the present study is that the 50% morphs created from a common component and item-specific components can look to pigeons substantially similar, but discriminably different, to one another.