Pigeons (Columba livia) learn visual categories based on angle of movement, but not angle of orientation

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Abstract:
Pigeons learned to categorize visual stimuli presented on a computer monitor. When categorizing moving objects based on speed and angle of travel, pigeons divided attention across both stimulus dimensions and performed nearly optimally. When categorizing objects based on size and angle of orientation, pigeons selectively attended to size, even when attention to orientation was required for optimal performance. Results indicate that categories based on angle can be relatively easy or difficult for pigeons, depending on whether angle represents an orientation or a direction of travel.

Introduction:
In research on categorization, there has typically been a tradeoff between realism and quantifiability of stimuli. However, following Maddox and Ashby (1990), recent investigations have used normal distributions to mimic some of the important features of naturalistic categories, while still working with category structures that can be subjected to rigorous statistical analysis. For example, Herbranson, Fremouw & Shimp (1999, 2002) have used this method to investigate pigeon categorization, and shown nearly optimal performance on categories of rectangles that vary in terms of height and width, and on categories of moving objects that vary in terms of speed and direction. Based on these data, rectangles and vectors seem to be perceptually integral. In comparison, Shepard circles are important in cognitive psychology because they are perceptually separable; it is difficult to optimally integrate information from the two dimensions of orientation and size. If pigeons' show similar results, Shepard circles would constitute an important tool for further research on perception and categorization. However, several research programs suggest that pigeons might not categorize Shepard circles in the same way humans do. First, note that differences in orientation are notoriously difficult (though not impossible) for pigeons to learn, despite being trivially easy for humans. Second, consider the lack of a mental rotation effect in pigeons, which further suggests that pigeons may perceive angle in a fundamentally different way from humans (Hollard & Delius, 1982). The present experiment is designed to investigate whether pigeons' categorization based on angle is different from humans, and if so, under what conditions it is different.

Method:
36 male silver king pigeons (Columba livia) were maintained at 80% of free-feeding weight. Sessions took place daily in operant chambers equipped with video monitors and peck-sensitive screens. On each of 80 daily trials, pigeons viewed a stimulus drawn from a bivariate normal distribution (see figure 1). Birds then responded by pecking one of two illuminated squares located to the left and right of the stimulus. Left responses were reinforced in the presence of stimuli generated from one category and right responses were reinforced in the presence of stimuli generated from a second category. Each experimental condition used one of two kinds of stimuli: Semi-circles having a particular diameter and orientation ("Shepard circles"), or dots moving with a particular speed and direction ("vectors"). Optimal performance required either selective attention to one of the two dimensions, or divided attention across both, yielding the six possible conditions shown in figure 2.

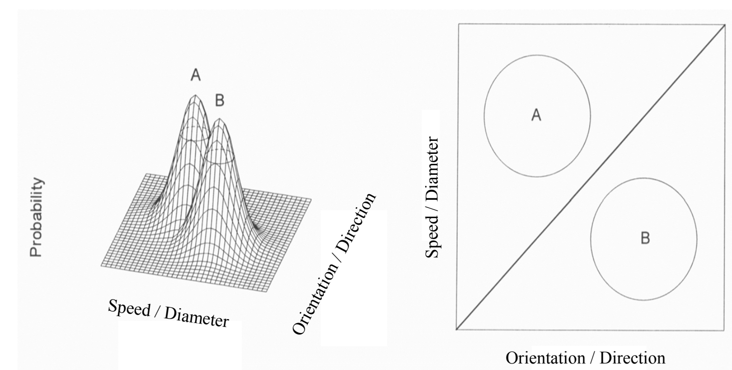

Figure 1: Bivariate normal distributions used to generate stimuli.

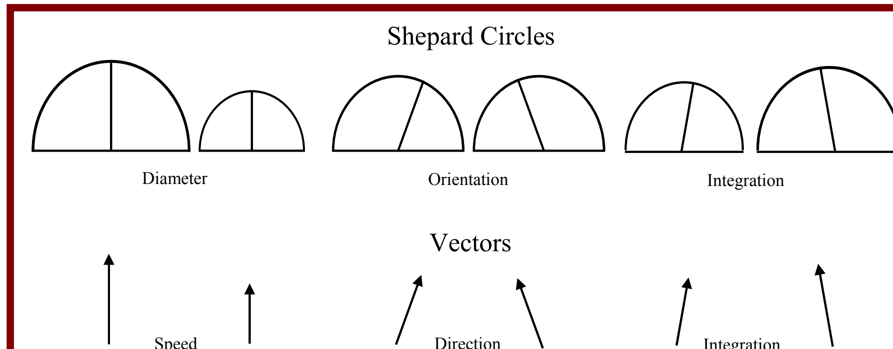

Figure 2: Category prototypes for each of the six conditions.

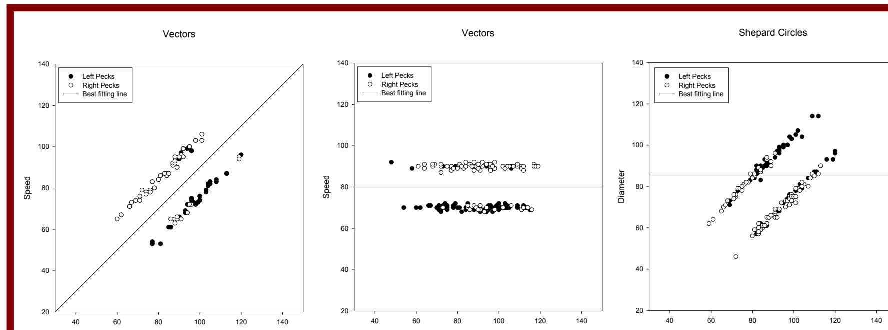

Figure 3: Examples of Stimulus spaces and best-fitting decision rules for three birds.

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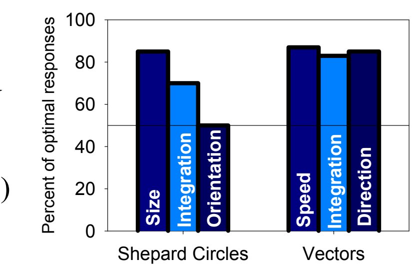
Results:
Vector stimuli: Birds accurately categorized over 80% of vector stimuli across the final 5 days of training, whether categories were based on speed, direction, or both. In each case, the decision bound that best described individual birds' performances approximated the optimal bound (see figure 3, left and center panels).



Shepard Circle Stimuli: Birds achieved high levels of accuracy and approximated the optimal decision rule only when required to attend selectively to size. Greater than chance (but still sub-optimal) performance on the integration condition was apparently achieved by selectively attending to size (see figure 3, right panel). For categories based only on orientation, accuracy was indistinguishable from chance

Discussion:
Pigeons apparently can learn categories based on angle of movement quite easily, whereas categories based on angle of orientation are considerably more difficult (though perhaps not impossible with extensive training). These results were obtained even when the two stimulus types were balanced so that the angles of movement and orientation were identical on the presentation screen. Thus, it seems that Shepard circles may not be useful for the investigation of pigeon categorization in the same way that they are useful for the investigation of human categorization. As of now, there is still no obvious stimulus for pigeons that mirrors the perceptual separability of Shepard circles in humans. The source of this inter-species difference may be consistent with Hollard & Delius's (1982) explanation of rotational invariant pattern recognition in pigeons: the tendency for humans to see objects in a consistent upright canonical orientation has allowed them to shed a rotation-invariant system still present in birds.

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