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Statistical processing: computing the average size in perceptual groups

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Abstract

This paper explores some structural constraints on computing the mean sizes of sets of elements. Neither number nor density had much effect on judgments of mean size. Intermingled sets of circles segregated only by color gave mean discrimination thresholds for size that were as accurate as sets segregated by location. They were about the same when the relevant color was cued, when it was not cued, and when no distractor set was present. The results suggest that means are computed automatically and in parallel after an initial preattentive segregation by color.

Keywords: Size; Perceptual groups; Mean; Automatic processing

The trees in a forest, the grass in a field, a flock of birds, the cars in a parking lot, are seen as groups of similar but not identical objects about which we may not need to store individuating information. For most purposes a description of their general statistical properties, such as the mean value, the range, the variance and the distribution on a number of dimensions, will meet our everyday needs. Ariely (2001) proposed that the visual system represents overall statistical properties when sets of similar objects are present. He showed that the mean size is perceived more accurately than the individual sizes in a display of disks of varied sizes, and that there is little effect of the number of disks.

Our hypothesis is that statistical descriptors are computed automatically when attention is distributed over the display and the scale is set to that of individual elements (Chong & Treisman, 2003). We showed that judgments of the mean size of a set of circles are almost as accurate as judgments of the size of a single circle presented alone, and that they are little affected either by exposure duration or by delay, suggesting an automatic and parallel process. We confirmed that the judgments involved computing the mean size of an array by showing that comparisons were almost as accurate when the distributions differed as when they were the same, using sets drawn from normal distributions, rectangular distributions, distributions with just two equal peaks, or homogeneous distributions. More recently we have tested the automaticity of this averaging process using another criterion,—the absence of interference from a concurrent task. Judgments of mean size could be combined without decrement with tasks requiring either distributed attention (search for an open circle among closed circles) or global attention (discriminating the orientation of a large rectangular frame around the display). On the other hand, tasks requiring either focused attention to individual circles in the relevant set (search for a closed circle among open circles) or

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focused attention to an irrelevant stimulus (discriminating the orientation of a small foveal rectangle) did interfere with judgments of mean size (Chong & Treisman, in press).

In these experiments, we controlled the density and the number of elements, and we restricted the display to just the relevant elements. In natural scenes, the elements may vary not only in size but also in other quantitative attributes. In computing the mean size, can we ignore other parameters like the density and the numerosity of the elements, or are these different quantities pooled in some aggregate description of quantity? The effects of density and numerosity on statistical processing have been studied in other domains of visual perception. Dakin (1997) explored the effect of density in computing the average orientation of Glass patterns with a dipole separation of 8′. Discrimination whether the average orientation was clockwise or anticlockwise relative to the vertical was poor for very sparse patterns (8 dipoles/deg^2), but rapidly improved with an increasing number of dipoles, showing little effect of density above about 64 dipoles/deg^2. Allik, Tuulmets, and Vos (1991) investigated possible effects of size on visual number discrimination using two random dot-patterns. Participants compared a reference pattern that was always composed of 32 randomly distributed dots to a test pattern with one of five magnifications and with a slightly smaller or larger number of dots. They found that participants could accurately judge the number of items irrespective of the size of the stimulus pattern, suggesting size invariance in number discrimination. In our first experiment we explored the effects of density and of number on judgments of the mean size of sets of circles, to see whether participants could abstract the average size from other measures of quantity like the ratio of filled to unfilled area or the numerosity of the displays.

Natural scenes usually contain many disparate sets of elements. It might be meaningful to compare the sizes of pebbles in a dense pile with those scattered more sparsely around the area, but it would hardly be useful to average the sizes of the pebbles with the sizes of the grains of sand in an adjoining area, or with the fallen leaves scattered amongst the pebbles. In summarizing the sizes, we must pre-sort and select the items that should and that should not be pooled. By attending to a defined area, we may be able to generate statistical descriptors specifically for the elements it contains. Indeed this was the task we used in our earlier experiments (Chong & Treisman, 2003). Participants had no difficulty comparing mean sizes across the left and right visual fields. But what if the sets are composed of two types of elements that are spatially intermingled? Perceptual grouping based on differences in orientation and shape can occur even with randomly mixed sets (Beck, 1966). Does the computation of mean size follow perceptual segregation of the scene into separate groups, or are all the items in a given area pooled together? Can we selectively average a subset of randomly mixed elements defined by particular features such as color, shape, orientation or motion? Does this happen automatically and in parallel for all the different perceptual subsets in a scene, or must we choose in advance? In Experiments 2 and 3, we explore the perceptual structuring that constrains the averaging process and makes it useful to us in the real world.

1. Experiment 1

In the first experiment, we tested the effects of number and of density on discriminations of the mean size of circles in two spatially segregated arrays. One possibility is that the visual system forms a general representation of the total stimulation coming from a given area. This will be perfectly correlated with the mean size if the number and density are held constant (as in our earlier experiments), but such a correlation is seldom present in the real world. It is important to find out to what extent we are capable of separating out these various descriptors when they vary either independently or in partially correlated fashion. We presented displays of 8 circles in either a dense array (0.139 circle/deg^2) or a sparse array (0.075 circle/deg^2) and displays of 16 circles in a dense array (0.149 circle/deg^2). Participants compared the mean sizes of elements in two arrays (presented in the right and the left visual field) that were either matched in number and density or mismatched. To ensure that they were computing the mean size rather than, for example, the largest size or the mode, one array varied the number of instances of two fixed sizes and the other varied the sizes of two sets with equal numbers of instances.

2. Methods

2.1. Participants

Seven participants including the first author participated in the experiment. All were members of Princeton University. All had normal or corrected-to-normal vision.

2.2. Apparatus and stimuli

The stimuli were created with the Psychophysics Toolbox (Brainard, 1997) and presented on the screen of an Apple 17″ Monitor. The monitor was driven by a Macintosh G3, which also performed all timing functions and controlled the course of the experiment. Participants were seated approximately 76 cm from the screen, at which distance a pixel was approximately