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A direct comparison of visual discrimination of shape and size on a large range of aspect ratios

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ABSTRACT

Participants viewed pairs of ellipses differing in size and aspect ratio (short axis divided by long axis length). In separate experiments with identical stimuli participants were asked to indicate the larger or the more circular ellipse of the pair. First, the size discrimination thresholds decreased with an increase in the circularity of the ellipses. Second, size discrimination thresholds were lower than aspect ratio thresholds, except for the circle and more elongated ellipses where both were similar. Third, there was also an effect of size on aspect ratio discrimination such that larger stimuli appeared more circular.
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1. Introduction

There exist many shapes like squares, rectangles, triangles, ellipses and every shape has some properties like size, orientation, perimeter and aspect ratio, etc. Shape discrimination and recognition require the discrimination of these properties among shapes and we have to do such discriminations among shapes in daily life.

There have been a number of studies on aspect ratio and size discrimination performance of two dimensional shapes. Regan and Hamstra (1992) measured the accuracy in judging the aspect ratio ($\phi = \frac{\ell_v}{\ell_h}$) of an ellipse with ℓ_v and ℓ_h as vertical and horizontal sides respectively (Regan, 1992). They asked participants to judge whether the aspect ratio of a test ellipse (ϕ_{test}) was greater or less than the aspect ratio of a reference ellipse (ϕ_{ref}). The area ($\alpha = \pi\ell_v\ell_h$) of the reference (α_{ref}) and the test ellipse (α_{test}) was varied randomly in each of the successive presentations to ensure that participants discriminated ellipses on the basis of the aspect ratio rather than ℓ_v, ℓ_h or ($\ell_v - \ell_h$). They found that the just discriminable change of aspect ratio was least when reference stimuli were circular ($\phi_{ref} = 1$) and gradually increased for more elongated ellipses. They also reported that there is no significant difference in performance for rectangles and ovals.

Liu, Dijkstra, and Oomes (2002) investigated orientation perception of 2-D shapes (Liu, 2002). The task in their experiment was to set the orientation of a probe (collinear line segments on either side of the ellipse) to the orientation of the long axis of the ellipse. Their research demonstrates that the root mean square bias and circular standard deviations of settings have a linear relationship with the roundness of the ellipse. They defined roundness as a transformed aspect ratio. The performance increased with decreasing roundness. Their results were also consistent with previous findings on the oblique effect: the accuracy of probe settings was higher for cardinal orientations as compared to oblique orientations.

Morgan (2005) performed experiments with the hypothesis that discrimination thresholds of aspect ratio and size can be explained from the discrimination thresholds of height and width (ℓ_v and ℓ_h). According this hypothesis, the area and aspect ratio are computed from independent measures of noisy width and height estimates and the square root of the sum of the squared thresholds of height and width should be equal to the threshold of area and aspect ratio (Morgan, 2005). He found that in case of ellipses, the accuracy for aspect ratio was higher than predicted by the combination of the noisy width and height thresholds and for rectangles it was worse, suggesting that curvature could be a cue to shape in case of ellipses. He found that for both ellipses and rectangles, the accuracy for area was lower than predicted by the combination of noisy width and height thresholds suggesting that participants could base their decisions on a variety of heuristics derived from single dimensional codes.

Nachmias (2008) studied the effect of jittering on size and shape discrimination of rectangles and ellipses. He randomly jittered the height and width of the rectangles and ellipses within

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±20% of the reference value. He asked participants to compare the height, area and aspect ratio of the presented rectangles and ellipses. He found that jittering reduces the discrimination for height, size and aspect ratio although less for aspect ratio than size and height. Nachmias (2010) also performed experiments to compare the discrimination of size and shape of rectangles and ellipses. He asked participants to choose the taller member between the pairs of stimuli of the same aspect ratio but different SIZE (block) or of different SHAPE (block) but the same size. He found that performance of height discrimination is better in shape blocks than in size blocks. He suggested that perhaps both size and shape comparisons are always made and combined to determine subjects' response.

The literature seems to suggest that the properties of shapes cannot be estimated independently by the visual system. We investigate this in the first experiment with a design similar to similar to Regan (1992) but with a statistical analysis of the response data focused on revealing the contribution of stimulus characteristics on shape perception. In the second experiment, we investigate aspect ratio and size discrimination to find out which of the two is easier. The previous studies lack a direct comparison of both visual tasks for a range of aspect ratios. In the second experiment, we also investigate how size discrimination changes with the shape of the stimuli.

2. Experiment 1

Our hypothesis is that there are shape characteristics other than aspect ratio which are contributing to the aspect ratio discrimination threshold. These characteristics could be a difference of the orientation or the area of the stimuli. Moreover, all previous studies kept the orientation of the shapes fixed, potentially making the task easier. Thus we randomized the orientation of the test and reference shapes. We investigate with a slightly larger range of aspect ratios than used in the previous studies (Morgan, 2005; Nachmias, 2008, 2010; Regan, 1992).

2.1. Method

2.1.1. Apparatus and stimuli generation

Green ellipses were generated on a Philips 19″ SXGA LCD monitor with gray background. Refresh rate of the monitor was 60 Hz. Screen resolution was 1280 × 1024 pixels. A chin rest was used to fix the head movements of the subject. There was a viewing distance of 114 cm between middle of the screen and the subjects' eye position. Line width of the stimuli was 1.5 mm. We used six reference aspect ratios of 1/10, 1/6, 1/3.2, 1/2, 1/1.4 and 1. An ellipse with aspect ratio closer to one is more circular as circle has aspect ratio of one. The method of constant stimuli was used (test levels were sampled without replacement from a predetermined sets of values). Each trial consisted of a presentation of a reference and a test stimulus on the same screen. The two-alternative forced choice (2AFC) method was used with randomly presenting test and reference stimuli on left or right positions on the screen. Participants had unlimited viewing time, i.e., they were free to take as much time as they wanted.

Fig. 1 shows a screen shot of the stimuli as presented in the experiment. For each of the reference aspect ratios, there were ten test aspect ratios. In total, there were 6 (reference aspect ratios) × 10 (test aspect ratios) × 20 (repetitions) = 1200 stimulus presentations per observer. These 1200 presentations were presented in a random order. For reference aspect ratios of 1/10, 1/6, 1/3.2, and 1/2, the test aspect ratios were ±65% of the reference aspect ratios and evenly spaced on the log scale. As we defined aspect ratio as the ratio of the short and long axis length $(\phi = \frac{s}{\ell})$,

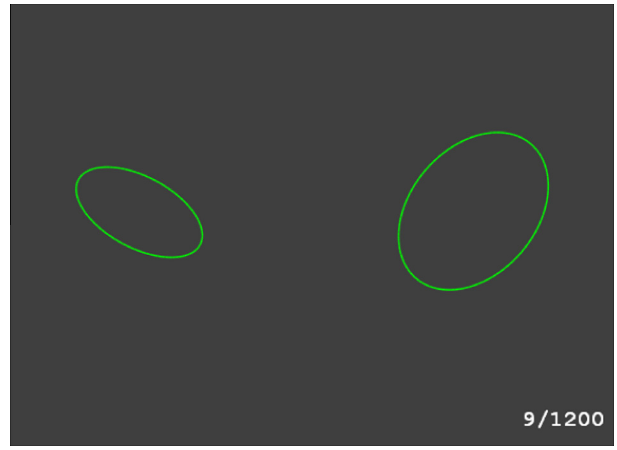

Fig. 1. Illustration of the stimuli in the first experiment. The values of aspect ratio, area and orientation for the reference stimulus are 0.7143 (1/1.4), 13.35 cm^2 and 49.23° respectively. The values of aspect ratio, area and orientation for the test stimulus are 0.5143, 5.86 cm^2 and 151.95° respectively.

the reference and test aspect ratios cannot be greater than 1 which creates a problem when the reference is the circle ($\phi = 1$). For the reference aspect ratio of 1, we used only five test aspect ratios with values 0.65, 0.71, 0.79, 0.87, 0.95. For the psychometric function of a reference aspect ratio of 1, these five test aspect ratios were presented twice and their responses were swapped to create fictitious aspect ratios of 1/0.95, 1/0.87, etc. To avoid the same issue with the reference aspect ratio of 1/1.4, test aspect ratios were ±72% of the reference aspect ratio. The area of both the reference and the test stimuli was varied randomly in each presentation from 5 cm^2 to 17 cm^2. The placement and the orientation of the stimuli on screen were also varied randomly. The purpose behind this random variation of the area, placement and orientation was to eliminate as much as possible clues to make sure that subjects would only discriminate between aspect ratios of the stimuli.

Subjects were asked to choose which of the two presented ellipses appeared more circular. Subjects were asked to press the right arrow key, if the right ellipse appeared more circular and the left arrow key, if the left ellipse appeared more circular. We recorded number of times the test stimuli were chosen more circular. The presentation of the stimuli and the collection of the response data were performed using the psychophysics toolbox (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997) in Matlab (R2009b).

2.1.2. Subjects

There were six subjects, five males and one female. All participants provided consent in accordance with the Radboud University Institutional Review Board. Authors P_1 and P_5 were the authors of this study.

2.1.3. Data analysis

The response data of each participant for each reference aspect ratio was fitted with probit regression. Each predictor was constructed from the $\log_{10}$ of the ratio of the test and and reference values. Following two models were used

$$M_\phi = \Phi\left(\beta_\phi \log_{10}\left(\frac{\phi_{test}}{\phi_{ref}}\right) + \beta_0\right) \quad (1)$$

$$M_{\phi\alpha} = \Phi\left(\beta_\phi \log_{10}\left(\frac{\phi_{test}}{\phi_{ref}}\right) + \beta_\alpha \log_{10}\left(\frac{\alpha_{test}}{\alpha_{ref}}\right) + \beta_0\right) \quad (2)$$

where Φ is the cumulative distribution function of the standard normal distribution. β_ϕ, β_α and β_0 are the coefficients of aspect ratio, size and constant respectively. The appendix explains that

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