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.

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 \( \frac{v}{h} \) of an ellipse with \( \ell_v \) and \( \ell_h \) as vertical and horizontal sides respectively (Regan, 1992). They asked participants to judge whether the aspect ratio of a test ellipse \( \left( \frac{v_{test}}{h_{test}} \right) \) was greater or less than the aspect ratio of a reference ellipse \( \left( \frac{v_{ref}}{h_{ref}} \right) \). The area \( (\pi \ell_v \ell_h) \) of the reference \( (\ell_v \ell_h) \) and the test ellipse \( \ell_{test} \) was varied randomly in each of the successive presentations to ensure that participants discriminated ellipses on the basis of the aspect ratio rather than \( \ell_v \ell_h \) or \( (\ell_v - \ell_h) \). They found that the just discriminable change of aspect ratio was least when reference stimuli were circular \( \left( \frac{\ell_v}{\ell_h} \approx 1 \right) \) 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 \( (\ell_v \ell_h) \). 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...
±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 Nachmias (2010) 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 set 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 presented 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 ($\phi = \frac{b}{a}$), 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 the 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 $P_3$ 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 reference values. Following two models were used

\begin{align}
M_\phi &= \Phi\left(\beta_0 + \beta_1 \log_{10} \left(\frac{\Phi_{\text{test}}}{\Phi_{\text{ref}}}\right) + \beta_0\right) \\
M_{a\phi} &= \Phi\left(\beta_0 + \beta_1 \log_{10} \left(\frac{\Phi_{\text{test}}}{\Phi_{\text{ref}}}\right) + \beta_2 \log_{10} \left(\frac{A_{\text{test}}}{A_{\text{ref}}}\right) + \beta_0\right)
\end{align}

where $\Phi$ is the cumulative distribution function of the standard normal distribution. $\beta_0$, $\beta_1$, and $\beta_2$ are the coefficients of aspect ratio, size and constant respectively. The appendix explains that

![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$^\circ$ respectively. The values of aspect ratio, area and orientation for the test stimulus are 0.5143, 5.86 cm$^2$ and 151.95$^\circ$ respectively.](image)
exclusion of possible contributing predictors results in underestimation of the other coefficients and hence it is good practice to consider all reasonable predictors and test for their significant effect. The discrimination threshold is defined as the inverse of the coefficient of the aspect ratio predictor. Standard errors of aspect ratio discrimination thresholds were calculated from standard errors of the aspect ratio coefficients by using the method of propagation of errors. The higher the value of the discrimination threshold, the more difficult it is for a participant to discriminate between the presented stimuli. While we included a regression constant \( b_0 \) in the models, it was never significant for any of the participants in any of the conditions. This indicates an absence of response bias.

The first model \( (M_1) \) assumes that subject's responses are only based on the aspect ratios of the presented ellipses. The second model \( (M_{a\alpha}) \) not only assumes the aspect ratio but also the size as a contributing variable to the response. The lower the deviance the better the fit. As the models are nested, model \( M_{a\alpha} \) will always have a smaller deviance. To find the advantage of including the size predictor, we calculated the difference of the deviance between the two models. This difference follows a \( \chi^2 \) distribution with \( k = 1 \) degrees of freedom. At one degree of freedom, a \( \chi^2 \) value of 3.84 is significant at a level of 0.05.

Due to the dependency of aspect ratio discrimination thresholds for different reference aspect ratios through subjects, we performed a one-way repeated measures ANOVAs to find the difference among aspect ratio discrimination thresholds of six reference aspect ratios.

### 2.2. Results

We defer comparison of our results with results of Regan and Hamstra (1992) until the discussion part. Table 1 shows the difference of the deviance between two models \( M_y \) and \( M_{a\alpha} \). Subjects \( P_1, P_2, P_3 \) and \( P_4 \) show a significant difference between the models for all reference aspect ratios except for the circle. For participant \( P_3 \), the inclusion of the size predictor does not improve the fit, so for \( P_3 \) model \( M_y \) is sufficient to explain the response for all reference aspect ratios. For half of the reference aspect ratios, participant \( P_2 \) also shows that model \( M_{a\alpha} \) is better.

We also checked the difference of the deviance between model \( M_y \) and a model which also includes the difference of the orientation between the ellipses as a predictor. The latter was not significantly better, which suggests that the difference of the orientation does not contribute to aspect ratio discrimination. Next, we also checked a model with an interaction between \( \phi \) and \( \alpha \), which also did not result in a significant improvement of model fit.

Fig. 2 shows the aspect ratio discrimination threshold calculated from the coefficient of the aspect ratio predictor from model \( M_{a\alpha} \) because this model fits better for most participants. The aspect ratio discrimination threshold is plotted against six reference aspect ratios. Error bars show the 95% confidence interval which was calculated from standard errors of aspect ratio discrimination thresholds. The circle has the lowest threshold. The results of a one-way repeated measures ANOVAs show that there is a significant difference among shape discrimination thresholds by excluding as well including circle thresholds \((p < 0.0001 \text{ and } p = 0.0012 \text{ respectively})\). Thus not only the circle thresholds differ from the other ones but there is also a difference among the other thresholds. The exclusion of thresholds of both the circle and the 1/1.4 reference aspect ratio did not give a significant difference among aspect ratio thresholds of other reference aspect ratios which implies that the discrimination thresholds flatten off for more elongated ellipses.

Fig. 3 shows the ratio of size and aspect coefficients obtained from model \( M_{a\alpha} \) averaged across participants. This ratio is obtained by dividing the coefficient of the size predictor by the coefficient of the aspect ratio predictor. The positive sign of the ratio of coefficients implies that larger ellipses appear more circular to the participants and the magnitude of the coefficient ratios shows the effect of the size predictor relative to the aspect ratio predictor. The coefficient of the aspect ratio predictor is larger than the coefficient of the size predictor which makes the ratio very small or close to zero when there is no effect of the size predictor. Both inclusion and exclusion of the coefficient ratios of the circle in the ANOVA tests gave a significant difference among coefficients ratios \((p < 0.0001 \text{ and } p = 0.0017 \text{ respectively})\) which implies that the effect of the size predictor is different for the circle than for the other reference aspect ratios. Although Fig. 3 shows that the averaged ratio of size and aspect ratio coefficient for circle is negative, this negative effect of the size is not statistically significant.

### 3. Experiment 2

After observing the effect of size on aspect ratio discrimination, the second experiment was designed to compare aspect ratio and size discrimination on exactly the same set of the stimuli. In this way, we can figure out which of the two tasks is more difficult and how both aspect ratio and size affect each other in shape and size discrimination.

#### 3.1. Method

**3.1.1. Apparatus and stimuli**

The general apparatus was the same as used in Experiment 1. The same screen resolution, viewing distance and line width of stimuli were maintained. The presentation of the stimuli was similar as shown in Fig. 1.

**3.1.2. Experiment design**

Fig. 4 shows the design diagram of the second experiment. The same six reference aspect ratios of Experiment 1 were used, but reference size was fixed at 11 cm\(^2\) whereas it was chosen random in Experiment 1. The y-axis of the Fig. 4 shows the test sizes used in the experiment. In this experiment, the test aspect ratios were ±72% of the reference aspect ratios and equally spaced on log scale and swapping of the responses was performed for the reference aspect ratio of 1. The values of the size were between 8 cm\(^2\) and 15 cm\(^2\). In total, we used a 10 × 10 factorial design with ten test aspect ratios and ten test sizes. For each reference aspect ratio, the 10 × 10 stimuli were presented twice which made a total of 200 presentations for each reference aspect ratio and a total of 1200 presentations for the whole experiment. The orientation, order and left/right position of the stimuli were randomized. With this design, the aspect ratio and size discrimination tasks can be performed on the same set of stimuli.

**3.1.3. Subjects**

There were six participants in this experiment. Five participants \((P_1, P_2, P_3, P_4, \text{ and } P_5)\) also participated in the first experiment whereas \(P_6\) was different. All participants provided consent in

### Table 1

<table>
<thead>
<tr>
<th>Subjects</th>
<th>1/10</th>
<th>1/6</th>
<th>1/3.2</th>
<th>1/2</th>
<th>1/1.4</th>
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</table>
accordance with the Radboud University Institutional Review Board.

3.1.4. Data analysis

The analysis was the same as the first experiment. For each reference aspect ratio, the difference of the deviance between models $M_a$ and $M_{a\delta}$ was obtained from the residuals of a probit regression. Model $M_a$ only has the area predictor.

$$M_a = \Phi \left( \beta \log_{10} \frac{a_{\text{ref}}}{a_{\text{test}}} + \beta_0 \right)$$ (3)

The difference of the deviance between models $M_a$ and $M_{a\delta}$ reveals which of the two models better explains the response data. Just as for the shape response data, the coefficients of the size predictor were converted to discrimination threshold by taking the inverse.

3.2. Task 1: aspect ratio discrimination

The task was the same as in the first experiment: participants were asked to choose which of the two presented ellipses was more circular.

3.2.1. Results

Table 2 shows the difference in deviance between two models $M_a$ and $M_{a\delta}$. For all reference aspect ratios except the circle, model $M_{a\delta}$ has a significantly smaller deviance than model $M_a$ in case of participants $P_1$, $P_5$ and $P_6$. In this experiment, participant $P_3$ also showed an effect of the size on the discrimination for two reference aspect ratios (1/2 and 1/1.4) while participants $P_2$ and $P_4$ did not show an effect of the size on the aspect ratio discrimination except for a single reference aspect ratio (1/6 and 1/2 respectively).

The lines with $\times$ markers in Fig. 5 show the aspect ratio discrimination threshold obtained from model $M_{a\delta}$ for six different reference aspect ratios for each subject while the other lines with round markers show results for the size discrimination task which will be described in the next section. For convenience of comparison, we have put both together in one plot. The results are similar to the first experiment. Both inclusion and exclusion of the circle thresholds in one-way repeated measures ANOVA tests gave a significant difference among aspect ratio discrimination thresholds ($p < 0.0001$ and $p = 0.0031$ respectively). Results of an ANOVA test with exclusion of aspect ratio thresholds of both the circle and the 1/1.4 reference aspect ratio were not significant which confirms flattening of the aspect ratio thresholds for more elongated ellipses also in second experiment. A paired $t$ test did not give a significant difference between aspect ratio discrimination thresholds of Experiments 1 and 2 for participants $P_1$ to $P_5$, confirming that the small change in experimental conditions did not lead to a significant change in performance. We performed a paired $t$ test between size/shape coefficient ratios of Experiments 1 and 2 for participants $P_1$ to $P_5$ which did not give a significant difference among size/shape coefficient ratios of both experiments, confirming that the effect of size on aspect ratio discrimination thresholds is similar in both experiments.
3.3. Task 2: size discrimination

The apparatus, method and the procedure were the same as above. The same stimuli of the aspect ratio discrimination task were presented but the task was changed. Participants were asked to choose which of the two presented stimuli appeared bigger in size.

3.3.1. Results

Table 3 shows the difference in deviance between models $M_a$ and $M_{a,s}$ for six different reference aspect ratios. Overall, model $M_a$ with only size as predictor is better than model $M_{a,s}$ with size and aspect ratio predictors. For participants $P_1$, $P_2$ and $P_6$, the model $M_a$ is sufficient to fit the response data except for reference aspect ratios of 1/6 ($P_3$ and $P_5$) and 1/10 respectively. Only participants $P_4$ and $P_5$ demonstrate an effect of the aspect ratio predictor for most of the reference aspect ratios. Table 3 shows that the effect of the aspect ratio predictor on size discrimination is weak compared to the effect of the size predictor on aspect ratio discrimination as shown in Tables 1 and 2. However, for consistency we use model $M_{a,s}$ for the purpose of comparison between shape and size (Fig. 5).

The lines with a round marker in Fig. 5 show size discrimination thresholds for six different reference aspect ratios. Both inclusion and exclusion of circle thresholds in a one-way repeated measures ANOVA gave a significant difference among size discrimination thresholds of all reference aspect ratios ($p < 0.001$ and $p = 0.0019$ respectively). An ANOVA test excluding the size discrimination thresholds of both the circle and the 1/1.4 reference aspect ratio gave a significant difference among size discrimination thresholds of the other reference aspect ratios ($p = 0.0074$) which implies a decrease in size discrimination thresholds with an increase in circularity.

3.4. Comparison of shape and size

Fig. 5 shows that the size discrimination threshold is lower than the aspect ratio discrimination threshold for most reference aspect ratios especially for participants $P_2$ and $P_5$. To quantify which of the two thresholds is lower, we performed a paired $t$ test on the discrimination thresholds of each reference aspect ratio and Table 4 shows that there is a significant difference between the two tasks in case of a reference aspect ratio of 1/3.2, 1/2 and 1/4 with $p = 0.0346$, 0.0420, and 0.0074 respectively. We can also see the difference in thresholds of the two tasks in Fig. 6 where the thresholds are averaged across subjects. The size discrimination threshold is lower than the aspect ratio discrimination except for reference aspect ratios of 1/10, 1/6 and 1 which is also shown statistically in Table 4.

4. Comparison of thresholds with previous studies

We compare our results with previous studies of Regan (1992), Morgan (2005) and Nachmias (2008, 2010).

4.1. Method

We recorded discrimination thresholds from previous studies (Morgan, 2005; Nachmias, 2008, 2010; Regan, 1992) and converted them according to the definition of discrimination threshold in the current study i.e. the inverse of the coefficient of the aspect ratio or size predictor. The thresholds from Experiments 1 and 2 are obtained from the model with only aspect ratio predictor ($M_{a,s}$) for comparison with previous studies. Hence, the thresholds are on
average 15% higher than the thresholds calculated from the model $M_{\text{oa}}$, see Appendix for an explanation of this phenomenon.

The fifth experiment in Regan’s (1992) studies was on aspect ratio discrimination of ellipses. We took the aspect ratio discrimination thresholds from Fig. 6 of Regan (1992) and averaged across both reference aspect ratios because of the symmetry of thresholds on both sides of the circle and because we found no effect of ellipse orientation in the first experiment. Further, we averaged these thresholds across the four participants. Regan (1992) defined aspect ratio discrimination threshold as half of the difference between 75% and 25% points on psychometric function which we converted into aspect ratio coefficient by taking the difference of the normal cumulative distribution between 75% and 25% and then dividing this difference by 2. So

$$\frac{1}{\bar{p}_0} = \Delta_R \left( \Phi^{-1}(0.75) - \Phi^{-1}(0.25) \right)$$

where $\Delta_R$ is the discrimination threshold from Regan’s experiment. The left panel in the Fig. 7 shows the comparison of the aspect ratio discrimination thresholds obtained in the first and second experiment with thresholds from Regan’s (1992) study.

Figs. 2 and 5 in the study of Morgan (2005) show size and aspect ratio discrimination thresholds respectively for circle which are based upon the 18–82% points on the psychometric function which we converted into aspect ratio coefficient by taking the difference of the normal cumulative distribution between 82% and 18%.

Table 3

<table>
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<tr>
<th>Subjects</th>
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Table 4

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Fig. 5. Aspect ratio and size discrimination thresholds for all participants in the second experiment. Error bars show 95% confidence interval on aspect ratio and size discrimination thresholds.

Fig. 6. Discrimination thresholds of aspect ratio and size averaged across reference aspect ratios in the second experiment. Error bars show standard deviation of thresholds across subjects.

where $\Delta_R$ is the discrimination threshold from Regan’s experiment. The left panel in the Fig. 7 shows the comparison of the aspect ratio discrimination thresholds obtained in the first and second experiment with thresholds from Regan’s (1992) study.

Figs. 2 and 5 in the study of Morgan (2005) show size and aspect ratio discrimination thresholds respectively for circle which are based upon the 18–82% points on the psychometric function which we converted into aspect ratio coefficient by taking the difference of the normal cumulative distribution between 82% and 18%. Fig. 2 in the study of Nachmias (2008) shows size and aspect ratio discrimination thresholds for the circle which were obtained from the standard deviation of a fitted cumulative Gaussian using
psignifit version 2.5.6: a software package which implements the maximum likelihood method described by Wichmann and Hill (2001a). The standard deviation of the fitted psychometric function in his studies is equivalent to the inverse of the regression coefficient in our case. Nachmias (2008) used the natural logarithm of the aspect ratio and size predictors whereas we defined the aspect ratio predictor as \( \log_{10} \left( \frac{C_1}{C_2} \right) \) and the size predictor as \( \log_{10} \left( \frac{2A_1}{A_2} \right) \). So, we converted thresholds to base 10 logarithm. Similarly, we took size and aspect ratio discrimination thresholds for the circle from Fig. 11 of the study of Nachmias (2010) for both successive and simultaneous presentations of ellipses which we averaged and converted accordingly as described for Nachmias (2008). The right panel in Fig. 7 shows comparison of circle discriminations with Regan (1992), Morgan (2005) and Nachmias (2008, 2010).

4.2. Comparison

The results of Regan show a decrease in aspect ratio discrimination thresholds with an increase in the circularity and our study finds similar results (the results of the one-way repeated measures ANOVA test on discrimination thresholds in the first and second experiment). In contrast to our data, the inclusion and exclusion of the circle thresholds as well as thresholds of 1/1.4 and 1/2 reference aspect ratios in a one-way repeated measures ANOVA test on Regan’s data gave a significant difference among aspect discrimination thresholds of the other reference aspect ratios (inclusion of thresholds of circle: \( p < 0.00001 \), exclusion of thresholds of circle and 1/1.4 aspect ratios: \( p = 0.0001 \), exclusion of thresholds of circle, 1/1.4 and 1/2 aspect ratios: \( p = 0.0024 \)). We performed an unpaired \( t \) test between Regan’s data and our experiments, which did not result in a significant difference except for thresholds of reference aspect ratio of 1/6 from the second experiment. Generally, the findings of the current study are similar to the results of the Regan’s experiments in spite of the differences in experimental conditions of the both studies (see general discussion).

The right panel in Fig. 7 shows that aspect ratio discrimination thresholds for the circle in the first and second experiment are consistent with previous studies of Regan (1992), Morgan (2005) and Nachmias (2008, 2010) in spite of the differences in experimental conditions of all studies. The right panel in Fig. 7 also shows that there is little difference among size discrimination thresholds of all studies except for the study of Nachmias (2008) where size discrimination thresholds are considerably higher from others.

5. General discussion

It is prudent to compare models for aspect ratio and size discrimination with many possible predictors and care should be taken while calculating discrimination thresholds with probit or logit methods because these methods could underestimate the thresholds when not all relevant predictors are included (see Appendix). In the first experiment, on excluding circle thresholds we find on average a decrease of 17% in thresholds of the other reference aspect ratios when including the size as a predictor in the aspect ratio discrimination. In case of the second experiment, on excluding circle thresholds there is on average a decrease of 10% in thresholds of the other reference aspect ratio when including the size as a predictor. We do not find an effect of the size predictor on aspect ratio discrimination thresholds for the circle. The studies of Regan (1992), Morgan (2005) and Nachmias (2008, 2010) do not check alternate models. Regan (1992) also did experiments on rectangles and intersecting lines, but he did not perform analysis with size as a predictor. Table 1 shows that aspect ratio discrimination is influenced by the size of the presented stimuli. One reason could be that both aspect ratio and size are combined to a response in this discrimination task (Nachmias, 2010). Similar results have been reported by Krantz and Tversky (1975) on dissimilarity of rectangles. They found that shape and size do not contribute independently in perception of the dissimilarity between rectangles and perceived shape differences increase with perceived area. They also found large individual differences. Rectangles have no curvature. The effect of size on dissimilarity (Krantz & Tversky, 1975) of rectangles and similar findings of aspect ratio thresholds reported by Regan (1992) for rectangles and ellipses suggest that in case of ellipses, the curvature can be an extra cue used in aspect ratio discrimination, but not the only one information used by participants.

Although our experimental setup differed from the one used by Regan (1992), our discrimination thresholds are similar to their thresholds for ellipse stimuli. There are four differences between Regan’s experiments and ours. First: in our experiments, there is a simultaneous presentation of both stimuli on the screen as opposed to the successive presentation of the stimuli in Regan’s experiments. From the current study it appears that aspect ratio discrimination is independent of the presentation conditions:
participants in current experiments have almost the same range of aspect ratio discrimination thresholds as participants had in Regan’s (1992) experiments (shown in left panel of Fig. 7 and the unpaired t test between Regan’s data and current experiments did not result in a significant difference between thresholds). Second: the random variation of the orientation of the stimuli was fixed in Regan’s experiments. The difference of orientation between presented stimuli could affect discrimination but the current study could not find such an effect. The aspect ratio of the stimuli does affect orientation discrimination (Kennedy, Orbach, & Lofller, 2006; Liu, 2002) but the aspect ratio discrimination is independent of the difference in the orientation. The model with the difference of the orientation between presented ellipses as predictor did not improve the model fit. Third: the presentation time of the stimuli was fixed in Regan’s experiments. Time pressure is absent in our study. The participants were free to take as much time as they wanted. Fourth: we performed the analysis with both shape and size predictors while in their study only the shape predictor was used. The current study finds that the inclusion of both aspect ratio and size predictors affects the regression coefficients of each other in model comparison (Appendix). This extra analysis with a size predictor in the model reveals that larger ellipses appear more circular to the observer and this finding is consistent in both experiments.

Our study compares discriminations of shape and size by presenting exactly the same set of stimuli in both experimental tasks. We explore size discrimination on a large range of aspect ratios as opposed to the previous studies (Morgan, 2005; Nachmias, 2010). The size discrimination thresholds are overall smaller than the aspect ratio discrimination thresholds. The lower values of the size discrimination thresholds as compared with the shape discrimination thresholds in the second experiment demonstrates that size estimation involves lower noise than shape estimation. As by the design of the second experiment, aspect ratio thresholds are determined with size as a random variable, and vice versa. The overall smaller values of the size discrimination thresholds suggest that aspect ratio discrimination is more perturbed by size variation than size is perturbed by aspect ratio variation. These findings seem to be consistent with Morgan’s suggestion that size discrimination is essentially 1D and hence size discrimination is not affected by aspect ratio. The size discrimination thresholds show a trend of decrease in thresholds with an increase in the circularity of the ellipses (results of repeated measures one-way ANOVA on size discrimination thresholds of all reference aspect ratios) which is a similar finding to the aspect ratio thresholds.

The circle seems to be a special case where all participants performed equally well in both discrimination tasks. Most of the previous studies also demonstrate that participants are better at discriminating circles as compared to other shapes (Levi & Klein, 2000; Regan, 1992, 2006) and our study finds similar results in aspect ratio and size discrimination tasks which suggests that both discrimination tasks are not influenced by the different experimental conditions in different studies.

In summary, our study performs a detailed analysis of shape and size discrimination tasks on a large range of aspect ratios. We show that size of the ellipse affects the observer’s perception of its shape and vice versa. The effect of the size on the shape discrimination task is high for more elongated ellipses and small for more circular ellipses (Fig. 3), which is qualitatively similar to the decrease of discrimination thresholds with an increase in the circularity of ellipses (Fig. 6). The positive sign of the coefficients of the size predictor suggests that larger ellipses appear more circular to participants (Fig. 3). This effect of shape and size on the discrimination task of the other could be due to the activation of irrelevant feature detectors in the visual system (Prinzmetal, 1981, 1995; Prinzmetal, Diedrichsen, & Ivry, 2001). Further our study finds that both size and shape discrimination thresholds are quantitatively similar but the size discrimination thresholds tend to be lower (except for the circle and more elongated ellipses) than the shape discrimination thresholds. This suggests that visual system performs shape and size discriminations with different mechanisms.

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Appendix A. Generalized linear regression coefficients depend on inclusion of relevant predictors in the regression model

The rationale behind this appendix is to highlight the importance of considering all possible predictors while modeling the response variables. For example in modeling shape responses, possible predictors other than shape are size and difference of the orientation of the stimuli. The inclusion and exclusion of these predictors in the analysis reveals whether they influence the response or not. This appendix highlights that the coefficients of the predictors change in generalized linear regression modeling even when the predictors are uncorrelated or orthogonal. Karlson, Holm, and Breen (2012) reports similar issues that probit or logit models may underestimate the value of regression coefficients due to confounding variables.

As the aspect ratio and size predictor are orthogonal to each other, i.e. there is no linear correlation between them, one could expect that the inclusion or exclusion of a predictor would not lead to cause a change in the coefficient of a predictor as is the case for linear regression (Karlson, Holm, & Breen, 2012; Studenmund, 2006). This independence of the regression coefficient from the presence of other predictors does not hold for generalized regression models as we illustrate by simulation of a probit regression model (Fig. 8). Response data is created for a reference aspect ratio of 1/2 with model $M_{\text{Ref}}$. The size of the reference aspect ratio was varied from 5 cm$^2$ to 17 cm$^2$. The coefficient of the aspect ratio predictor is fixed ($\beta_\alpha = 10$) while coefficient of the size predictor ($\beta_s$) is changed from 0 to 9. The aspect ratio predictor was varied from 0.33 to 0.77 while size predictor was varied from 5 cm$^2$ to 17 cm$^2$.

![Fig. 8. Simulation of the probit model where the response is obtained from model $M_{\text{Ref}}$. The x-axis shows different values of the size coefficient ($\beta_s$) with fixed value of the aspect ratio coefficient ($\beta_\alpha = 10$).](image-url)
17 cm². Fig. 8 shows that the coefficient of the aspect ratio predictor does not change on fitting back response data with model \( M_{a} \); it remains at 10. But on fitting the same response data with model \( M_{a} \), the coefficient of the aspect ratio predictor decreases with an increase in the coefficient of the size predictor which is contrary to the linear least squares regression. The extent of this underestimation depends on the range of the predictors. When we limit the range of the aspect ratio predictor from 0.45 to 0.55 then probit regression behaves like least squares regression. The simulation of coefficients in Fig. 8 is created using the glmfit function of Matlab (R2009b). Thus it is wise to check possible alternative models when performing analysis with probit or logit regression.

References


