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TWO-DIMENSIONAL SYMMETRIC FORM DISCRIMINATION: FAST LEARNING, BUT NOT *THAT* FAST

ABSTRACT. Several authors have characterized a striking phenomenon of perceptual learning in visual discrimination tasks. This learning process is selective for the stimulus characteristics and location in the visual field. Since the human visual system exploits symmetry for object recognition we were interested in exploring how it learns to use preattentive symmetry cues for discriminating simple, meaningless, forms. In this study, similar to previous studies of perceptual learning, we asked whether the effects of practice acquired in the discrimination of pairs of shape with a specific orientation of the symmetry axis would transfer to the discrimination of shapes with different orientation of symmetry axis, or to shapes presented in different areas of the visual field. We found that there was no learning transfer between forms with very different axes of symmetry (90° apart). Interestingly, however, we found a transfer of learning effect to horizontally oriented symmetry axis from a condition with an axis of symmetry differing by 45°. Also it appears that some subjects took a longer time to learn than the typical "fast learning" paradigm would predict. Data showed that when observers practice discrimination of meaningless symmetric forms, consistent improvement in the performance occurs. This improvement is lasting over days, and it tends to be specific for the area of the visual field trained. We will discuss results from some of the observers whose learning was not "fast", but who actually improved with more practice and with large time intervals (1 day) between training sessions.

1. INTRODUCTION

Many real objects exhibit symmetry and psychophysical studies have shown that the processing of symmetry is, by and large, preattentive. We were interested in how the discrimination of such symmetric forms can be learned. The paradigm for our study is the seminal work of Fiorentini and Berardi (1980). They demonstrated fast (60–160 trials) perceptual learning of discrimination of complex gratings. Interestingly, their findings show the specificity of learning for orientation and spatial frequency of the stimuli and the fact that once learning is achieved it lasts for days and weeks.

The focus of this study is to examine the characteristics of perceptual learning (i.e., the improvement of a visual task with practice) of two dimensional meaningless elaborated forms with different orientations of

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symmetry. In a previous study, (Chou 1993) we found that for discriminating such forms presented in brief exposure, as expected, (Sutherland 1980) vertical symmetry was significantly easier than horizontal symmetry or oblique (45° to the left or right of the vertical). Thus, in order to not contaminate the interpretation of the learning experiment we did not use vertical symmetry.

In our experiments, observers can learn meaningless form discrimination, but they need nearly 400 trials to complete learning. This is much slower than the learning shown for complex gratings (Fiorentini and Berardi, 1980), vernier acuity (Poggio et al. 1992) or direction of motion in noisy displays (Vaina and Harris, this meeting). Thus, our data suggests that learning symmetric form discrimination is slower than the typical "fast learning" paradigm.

2. METHODS

2.1. *The Stimuli*

The basic stimuli used were the same as those used by Deame (1992), and Deame and Vaina (1992) for perception of object parts. The stimuli consisted of a circle with gaussian bumps added to the circumference. The diameter of the circle was held constant at 3 cm (which subtends 90 minutes of visual arc at the viewing distance of 60 cm), while the amplitude of the bumps was varied.

The bumps were generated by using the following formula:

$$(1) \qquad Y_{\text{bump}}(x) = \frac{A}{\sigma\sqrt{2\pi}} e^{-\left(\frac{x^2}{2\sigma^2}\right)}$$

Equation (1) was used to generate normal gaussian distributions. The parameter A determines the amplitude of the gaussian and σ determines the variance (see Figure 1).

A circle with gaussian bumps was used by Deame and Vaina to study part perception because such forms are devoid of meaning and they offer full control over all parameters (i.e. number, amplitude, variance, and location of bumps). The bumps change smoothly and do not introduce any discontinuities into the figure. The bumps may be added to any location on the circumference of the circle by converting the coordinate system to a polar coordinate system and the bumps may be added on top of an existing bump. An example of one test figure is shown in Figure 2.

For our investigation of symmetry, we used stimuli that exhibit symmetry (see Figure 3) along three different axes (horizontal, 45° counterclockwise from vertical, and 45° clockwise from vertical).

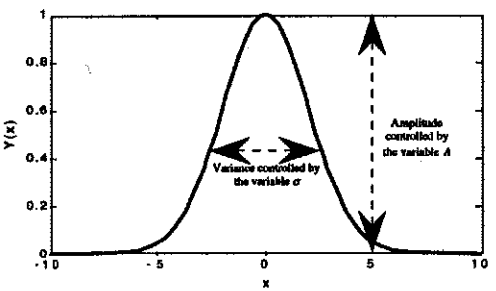

Fig. 1. A gaussian distribution generated by Equation (3.1) (A = 5.0, s = 2.0).

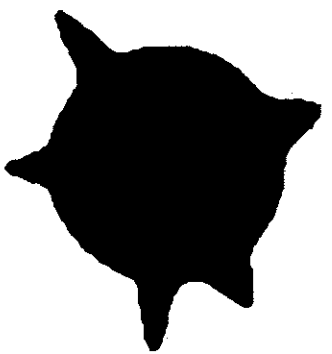

Fig. 2. Example of stimuli.

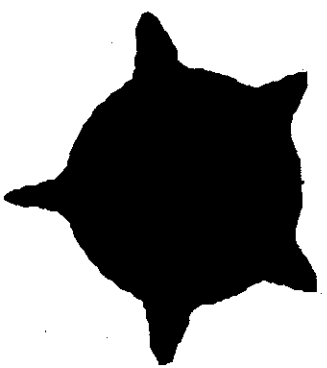

Fig. 3. Example of stimuli exhibiting horizontal symmetry.

2.2. *Viewing Conditions*

The subjects were seated in a dark room, at a distance of 60 cm from the computer screen, on which the stimuli were displayed. The subjects' heads

were unrestrained and their view was binocular. The subject was instructed to fixate on a provided fixation mark (a small black square of 0.3 cm which subtends 9 minutes of visual arc placed 4 degrees of visual arc to the upper or lower left or the lower right of the central figure). The purpose of the fixation point was to limit the stimuli figure to a specific region of the visual field.

2.3. *Subjects*

Four subjects, ranging in age from 17 to 46, participated in the learning test. All subjects had normal visual acuity and no known history of ocular or brain pathology.

2.4. *Experimental Procedures*

We used a same-different paradigm in a two temporal alternative forced choice discrimination task with the method of constant stimuli. Stimuli were presented in pairs: first the standard figure was displayed for 50 msec, then the screen was masked blank for 150 msec, after which the test figure was shown for 50 msec. In each pair, the test figure was either identical to the standard figure (same), or one bump on the test figure was increased in amplitude by approximately 50% or decreased in amplitude by approximately 33% relative to the standard figure (different). (These percentages represent the mean change over all figures displayed.) Prior to presenting a figure, a fixation mark was displayed and a delay of 30 msec was given to allow the subject to fixate on the mark. Prior to each figure presentation the computer emitted a beep. The subject entered the response by pressing specially designated keys on the computer keyboard. The learning task consisted of 200 stimuli presented in five blocks of 40 stimuli each. Subjects were required to rest for up to 15 minutes in between blocks.

Every figure had 5 bumps and mirror symmetry about the same axis. This test was administered twice a day over the course of four days. The first test was administered with lower left fixation and a −45 degree axis of symmetry. This test was repeated as the first test each day for the remaining three days to see whether learning was maintained. The second test each day differed from the first by either moving the fixation mark or by changing the orientation of the axis of symmetry. The subjects were informed of which axis of symmetry would appear in the figures for the test prior to administration of the test. The learning protocol is shown in Table I.

TABLE I

Testing protocol

Day #	Test #	Orientation of Axis	Location of Fixation Mark
1	1	−45°	lower left
1	2	+45°	lower left
2	1	−45°	lower left
2	2	−45°	lower right
3	1	−45°	lower left
3	2	−45°	upper left
4	1	−45°	lower left
4	2	±90°	lower left

3. RESULTS

Figures 4–5 show the performance of subjects on the learning tasks. In each figure, blocks 1 through 5 represent the first test and blocks 6 through 10 represent the second test. Each point in the graph represents the performance of the subject on one block of trials.

Figure 4 shows the results from one of the four subjects who trained on this task. Since subject WK was different from the others, his results are shown in Figure 5. He trained on only one condition (Test 1 in Day 1, in Table I). In Figure 5, Blocks 5 through 10 were given on the second day, and blocks 11–15 in the third day. The reason the protocol, described in Table I, was not followed was because this subject did not appear to be learning within the first five blocks. Therefore, we wanted to see whether, with more examples, this subject would learn.

4. DISCUSSION

4.1. *Learning is fast but not "very rapid", yet once learning occurs it is maintained*

All the subjects learned the tasks, yet the rate of learning differed from subject to subject. Figure 4, shows a typical example of learning. For this subject, as for the others (not shown here), once learning occurred, it was maintained over days. However, two interesting observations associated with the maintenance of learning can be made from the results. The first

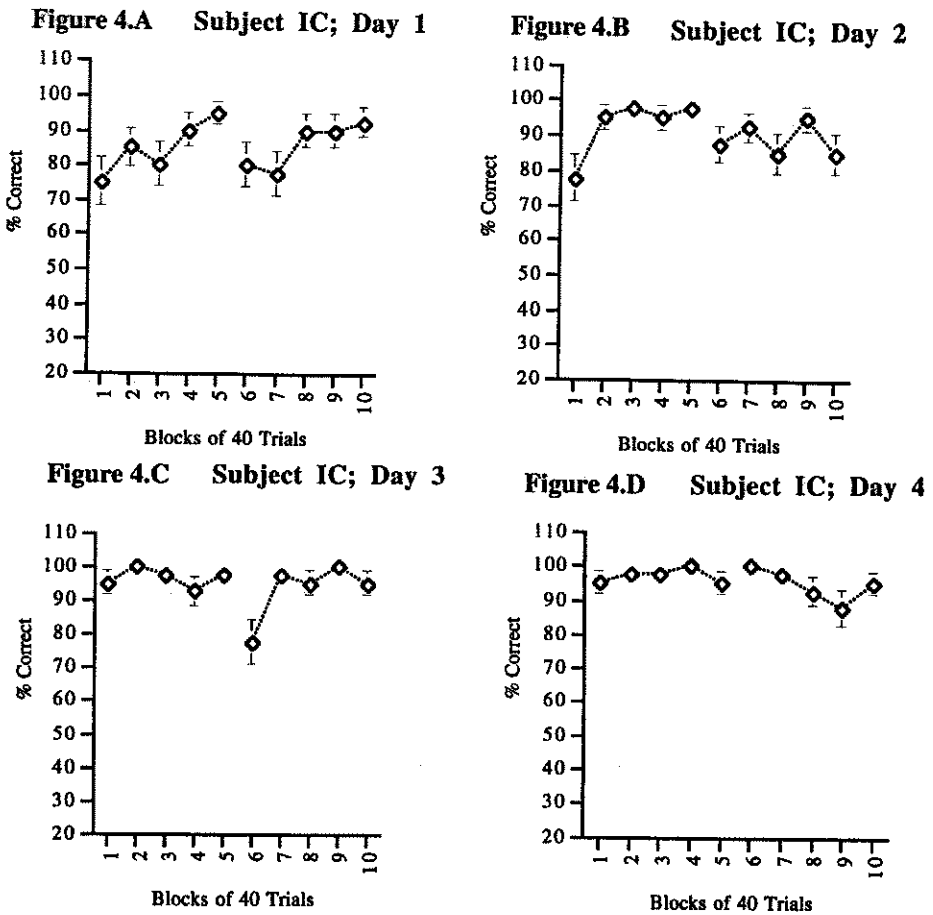

Fig. 4. Subject IC; (a) Day 1, (b) Day 2, (c) Day 3, (c) Day 4.

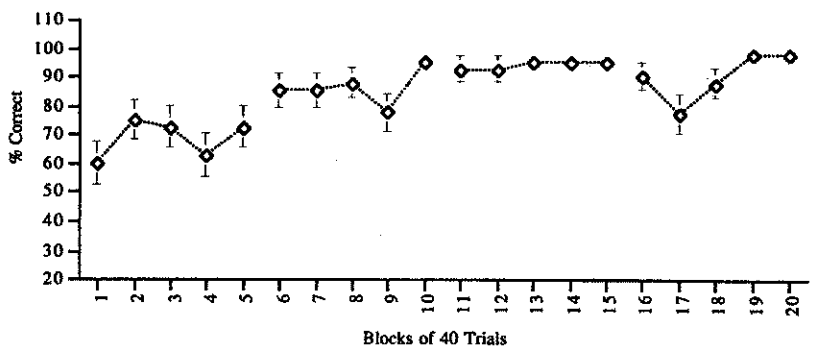

Fig. 5. Subject WK; Days 1–3.

observation concerns subject IC's performance on day 2 blocks 1 to 2. Figure 4.B shows that his performance began near 85% correct. It appears that this subject might have partly "forgotten", but the steep slope between block 1 and 2 in Figure 4.B shows that his relearning was very rapid. In fact it was much more rapid than the initial learning in Day 1. If learning of form discrimination means creating a useful representation in the cortex, it is possible that IC's performance and the slight "forgetting" might mean the representation created in the first day (20 trials) might not have been robust enough and thus it was not fully maintained. Indeed, the data in Figure 5, shows that at least some subjects require a large number of trials to learn this task. Interestingly, subjects such as WK in Figure 5, after those many trials, did maintain the learning very well.

It is possible that this is a task of form discrimination, the computations involved in carrying it out being more complex than those involved in vernier acuity or other tasks for which very rapid learning was reported.

4.2. Localization of the Perceptual Learning

Our results show that the learning was specific for the portion of the visual field in which training occurred. For example in Figure 4.A, subject IC improved from 75% correct to about 95% correct in blocks 1 through 5. When the axis of symmetry was changed from $-45°$ to $\pm 45°$ in block 6, IC's performance started again from 77.5% and then gradually his performance improved.

The learning did not transfer from the $-45°$ axis of symmetry to the $+45°$ axis of symmetry. But learning did transfer from 45° to the 90° (horizontal) axis of symmetry for the same location of the fixation mark. It is possible that the representation did not differ sufficiently in this case since the smallest rotation from $-45°$ to $\pm 90°$ was only 45°, whereas in the case of no transfer of learning the rotation from $-45°$ to $+45°$ symmetry axes was 90°. For learning discrimination of the direction of motion, for example, Ball and Sekuler (1987) showed that there was transfer of learning for directions differing less than 30°, but no transfer for directions differing greater than 45°.

Our previous study of the role of symmetry in object discrimination (Chou 1993), showed that subjects perform worse on horizontal symmetry than on the oblique symmetries. Thus, it is not clear whether there was indeed a lack of transfer or whether it was an effect of the difficulty of the task.

Two subjects were also tested for interocular transfer. This was done by covering one eye of the subject with an eye patch, and then the first learning test was administered to the subject. Then the eye patch was moved to the

subject's other eye and the same test was given to the subject. In both subjects the learning transferred interocularly. Since the first binocular cells in the visual system are found in layer IVB of Vl, it is clear that for this task learning occurred at least at the level of Vl, or very likely, higher.

We were interested to see whether the effects of learning transferred from one location in the visual field to another. Figure 4 shows a typical example of our findings. For the same orientation of symmetry (thus for the same object) learning did not transfer from fixation in the lower visual field to fixation in the upper visual field.

Thus, in conclusion we find that subjects can learn the discrimination of symmetrical objects, that the learning is fast but not "very fast", is maintained, and is specific to the area of the visual field trained. Further research is underway to determine under which specific conditions learning transfers.

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