

Stimulus specificity in perceptual learning: a  
consequence of experiments that are also stimulus  
specific?\*

Zili Liu  
NEC Research Institute  
4 Independence Way  
Princeton, NJ 08540, USA  
Email: zliu@research.nj.nec.com  
FAX: 609-951-2482

Lucia M. Vaina  
Intelligent Systems Laboratory  
Boston University  
Boston, MA, USA

March 29, 1995

Keywords: Perceptual Learning, Stimulus Specificity, Motion Discrimination,  
Stimulus Ensemble, Interleaved Stimulus Sequence

---

\*Please do not quote without permission.

## Abstract

Stimulus specificity is a typical result in perceptual learning studies — subjects’ improved performance after repeated trials under one stimulus condition  $A$  does not transfer to a different condition  $B$ . From the viewpoint of “*learning statistical properties from the stimulus ensemble*”, subjects may have learned specific aspects of  $A$ , but since  $B$  is not a sample from the  $A$  distribution, learning therefore does not transfer from  $A$  to  $B$ . We employed a novel paradigm of an interleaved stimulus sequence  $A$ - $A$ - $B$   $A$ - $A$ - $B$  .... Both  $A$  and  $B$  consisted of two sequential random dot motion stimuli. Subjects discriminated if the two directions in each condition were the same or different. Their performance for the  $B$  trials was higher than that for the first half of  $A$  trials, indicating a transfer  $A \rightarrow B$ , which is not predicted by a stimulus specific learning.

## 1 Introduction

Studies in perceptual learning have largely converged to a common finding: what is being learned is stimulus specific. That is to say, subjects’ improved performance under one specific stimulus condition (e.g., a two-line Vernier display in horizontal orientation) does not readily transfer to another stimulus condition (e.g., the same Vernier in vertical orientation [1]). Other examples include, to name just a few (see [2] for a recent review), orientation in stereopsis discrimination [3], orientation and spatial frequency in waveform discrimination [4], and direction in motion discrimination [5].

Often is this specificity interpreted as resulting from the underlying characteristic neurons, whose selective tuning (e.g., selectivity for orientation, spatial frequency, or motion direction) is responsible for the behavioral outcome of stimulus specificity. However, localizing stimulus specific neural adaptation does not necessarily mean that learning occurs only up to this level. In fact, the large body of perceptual learning phenomena appear arbitrary and lack a common underlying principle. We propose here that perceptual learning is “learning statistical properties from the stimulus ensemble”. More specifically, subjects’ increased sensitivity after repeated trials is directed toward some specific aspects of the stimulus in the experiments [6]. It is therefore not surprising that the improvement under one specific stimulus condition does not carry over to a novel stimulus that is unlikely a sample from the previous stimulus ensemble. In other words, stimulus specific experiments could have contributed to the stimulus specificity in perceptual learning.

In order to address the constraint under which perceptual learning is stimulus specific, we have employed a novel paradigm of interleaved stimuli by introducing a stimulus sequence  $A$ - $A$ - $B$ ,  $A$ - $A$ - $B$ , ..., where  $A$  and  $B$  are different stimulus conditions. The rationale is that should learning be stimulus specific,  $A$  and  $B$  will be independent, hence the rates of improvement for  $A$  and  $B$  should be in principle identical. On the other hand, should a transfer happen, more improvement should occur in  $B$  than in  $A$ , simply due to the fact that  $B$  is lagging behind  $A$ . Therefore, even if no transfer happens, the result is still interesting,

as stimulus specificity is then held in a more general context.

As a case study, we have employed a motion direction discrimination task, where A and B each stands for a pair of random-dot motion stimuli whose directions are to be discriminated, and the directions of the pair in A are opposite to those in B.

## 2 Method

### 2.1 Apparatus

Stimuli were presented on the monitor of a Macintosh Centris 650. A tube, whose inside was painted black, abutted the computer's screen. The viewing distance was 90 cm. Subjects looked at the monitor binocularly through the tube. The experiment was conducted in dark.

### 2.2 Stimulus

Each stimulus was consisted of 100 dots on a black background. Each dot was one pixel in size. The dots were evenly distributed within a circle of 240 pixels in diameter, which extended  $8^\circ$  in visual angle. (The screen resolution was about 19.38 pixels/cm.)

In the 10-frame motion stimulus, each frame lasted 44.7 *ms*. The motion of each dot from one frame to the next was as follows: its direction was sampled from a Gaussian distribution with a standard deviation of  $5^\circ$ , and a mean — an

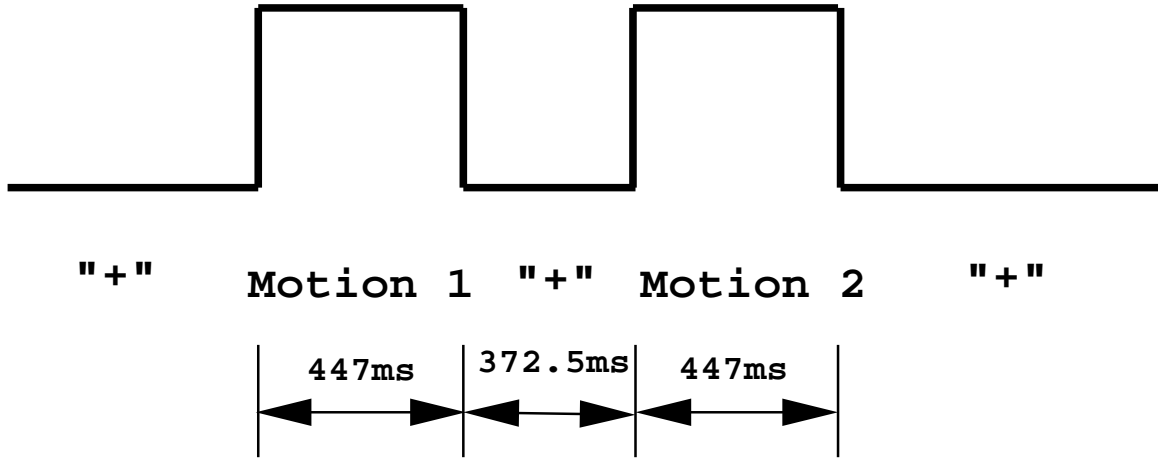


Figure 1: Experimental procedure in one trial (either A or B). Subjects chose if the stimuli of Motion 1 and Motion 2 moved in the same or different directions (see text).

experimental variable that will be explained in detail below. The displacement was 2.5 pixels plus the absolute value of a random number whose distribution was a Gaussian with a 0 mean and a standard deviation of 1 pixel.

### 2.3 Procedure

Subjects' task was to decide if two consecutive motion stimuli moved in the same or different directions. Subjects were instructed to respond as fast and as accurately as possible. Each trial started with a '+' fixation sign at the center of the screen, and was replaced by the first motion stimulus. The stimulus was then replaced by the same fixation sign that lasted for 372.5 ms. It was replaced by the second motion stimulus, whose dots' positions were independent

of those in the first. The mean of the Gaussian distribution, from which each dot's direction of motion was drawn, was either the same as the one in the first motion stimulus or different by  $30^\circ$ . The second motion stimulus was again replaced by the fixation mask for 372.5 ms (Figure 1). Subjects would press one of two keys to make the response. The computer beeped if the response was incorrect. This completed one trial, and the next automatically started.

The sequence of the trials followed the three-trial pattern of *A-A-B*, *A-A-B*, ..., where in a *A* trial, the direction of the motion was taken from a Gaussian distribution with a mean of either  $135^\circ$  or  $165^\circ$ ; whereas the mean of motion stimulus in *B* trial was opposite ( $180^\circ$ ), i.e., either  $315^\circ$  or  $345^\circ$ .<sup>1</sup> Subjects could take an optional rest at the end of each block, which was consisted of 78 trials. Subjects took 10 blocks total that lasted for about 30 minutes.

Subjects took 20 practice trials before the real experiment.

## 2.4 Subjects

Seven subjects, including the first author ZL, participated the experiment. Subject SV was aware of the experimental purpose, but not the technical details.

The rest of the five subjects were unaware of the experimental purpose.<sup>2</sup>

---

<sup>1</sup>The directions in *A* and *B* conditions were arbitrary, our pilot experiments found no difference of such a choice.

<sup>2</sup>One subject was a very experienced subject in the laboratory and was used to the way feedback was given in all other experiments in the laboratory, which was not consistent with the feedback employed in the current experiment. This subject was apparently confused by the feedback. (The subject, who scored remarkably in all the other experiments in the

### 3 Results

The scores of percent correct of discrimination between the first 260 trials of *A* condition and all the 260 trials of *B* condition were compared among the five subjects (excluding the first author). ANOVA yielded a significant effect of *B* (90.92%) over *A* (88.69%):  $F(1, 4) = 13.25, p < 0.022$  (when the data from the first author were included (*B*: 91.41%, *A*: 89.49%), the result was unchanged:  $F(1, 5) = 10.71, p < 0.022$ .) (Figure 2). This indicated that a positive transfer occurred from *A* to *B*.

Three of the five subjects above repeated the experiment the next day. Already no difference was found for the same comparison, suggesting that the advantageous improvement in *B* over *A* was fast and happening only in the first 260 trials. Indeed, when comparing the first with the second 260 trials of *A* in Day 1, although the scores in the second half were higher than those in the first for each subject, the difference fell short of significance:  $F(1, 4) = 2.64, p < 0.18$ . This again indicated that the advantageous improvement in *B* over *A* was fast. And more interestingly, this result also indicated that the advantageous improvement in *B* over *A* could not completely due to subjects' general task learning or warming up — a possibility one could never rule out completely even with the pre-test practice. Because if the advantageous improvement in *B* over *A* was laboratory, yielded the lowest score (78.85%) among the seven subjects, two of whom had no prior experience in psychophysics experiments.) For this reason, the data from the subject were excluded.

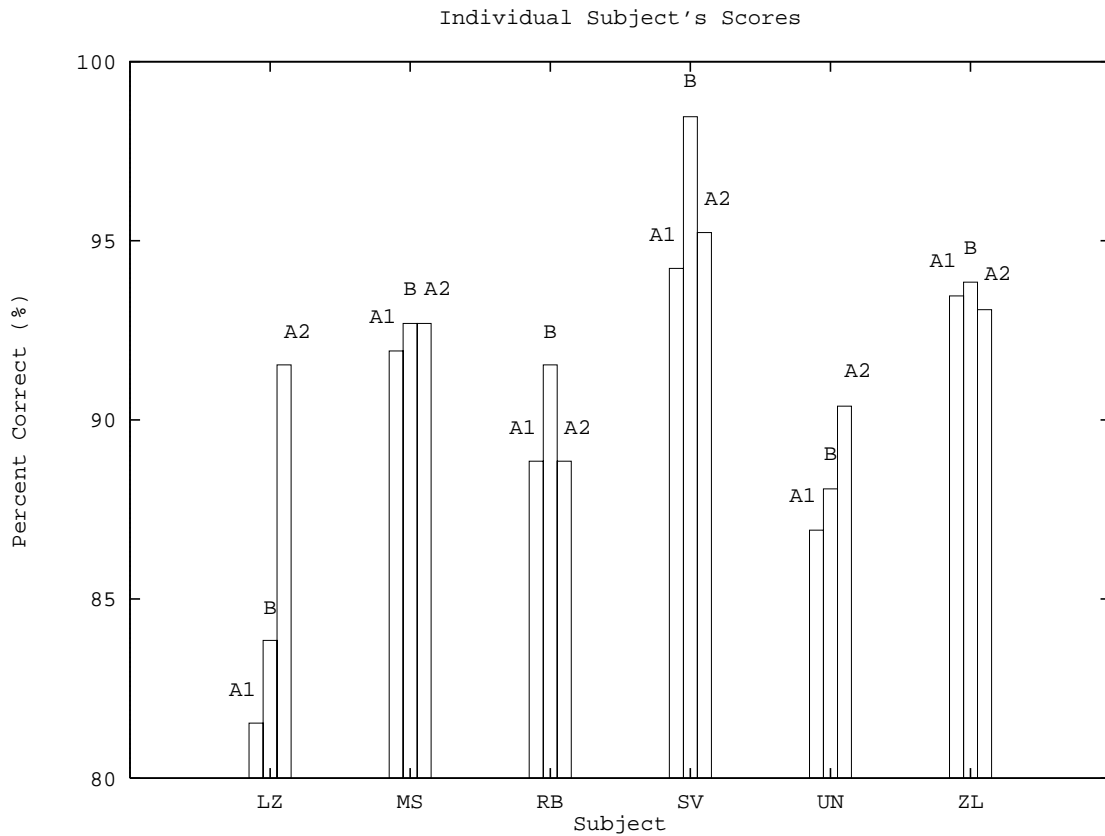


Figure 2: Individual subject's performance in the motion direction discrimination task with the sequence of  $A-A-B$ ,  $A-A-B$ ,  $A-A-B$ , ..., of 780 trials total (see text). The "A1" in the plot represents the first 260 trials of the  $A$  condition, and "B" all the 260  $B$  conditions, the second 260 trials of the  $A$  condition "A2" are also included for comparison. Subject SV was aware of the purpose of the experiment, the other four subjects were not. The score for the condition "B" is significantly higher than that for "A1" ( $F(1, 4) = 13.24, p < 0.022$ ). (Inclusion of the data from subject ZL (A1 : 93.46%, B : 93.85%), the first author, did not change the result:  $F(1, 5) = 10.71, p < 0.022$ .)



only due to a general task learning but not transfer, one would expect that the improvement of the second over the first half of *A* should be greater than that of *B* over the first half of *A*.

Figure 3 shows subjects  $d'$  scores, whose pattern is very similar to the subjects' percent correct scores. ANOVA from the five subjects yielded a marginal significant difference between *B* and *A2* (2.92 vs 2.51,  $F(1, 4) = 5.03, p < 0.088$ ). Inclusion of the subject *ZL* yielded: 2.96 vs. 2.60 ( $F(1, 5) = 5.10, p < 0.074$ ). These high  $d'$  scores indicated that the task was indeed relatively easy, so that subjects' percent correct was high even at the beginning of the task. It is therefore not too surprising that the absolute magnitude of advantage of *B* over *A1* was not substantial.

In fact, when looking at the subjects' percent correct performance as a function of the trials (Figure 4), it turns out that the advantageous performance of *B* over *A*, or the putative transfer, occurred during the first 100 trials or so. This is again consistent with the notion that the task was relatively easy and a fast learning occurred at the beginning of the task.

Finally, to document that learning indeed occurred during the experiment, the data from the two subjects who repeated the experiment on the third day, plus those from the first author, were analyzed with "day" as an independent variable. ANOVA yielded a significant effect for the improvement:  $F(2, 4) = 10.27, p < 0.027$ , indicating that a learning was indeed happening (see Figure 5).

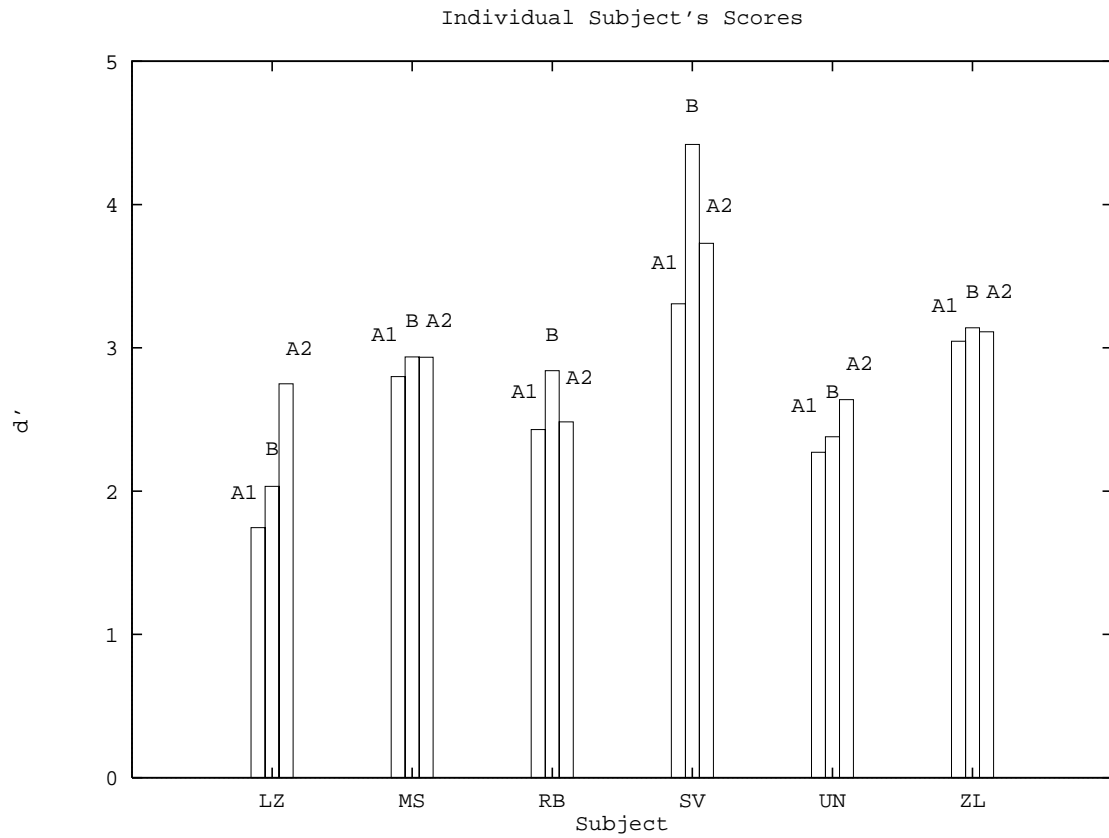


Figure 3: Individual subjects'  $d'$  scores. See the legend of figure above for more details.

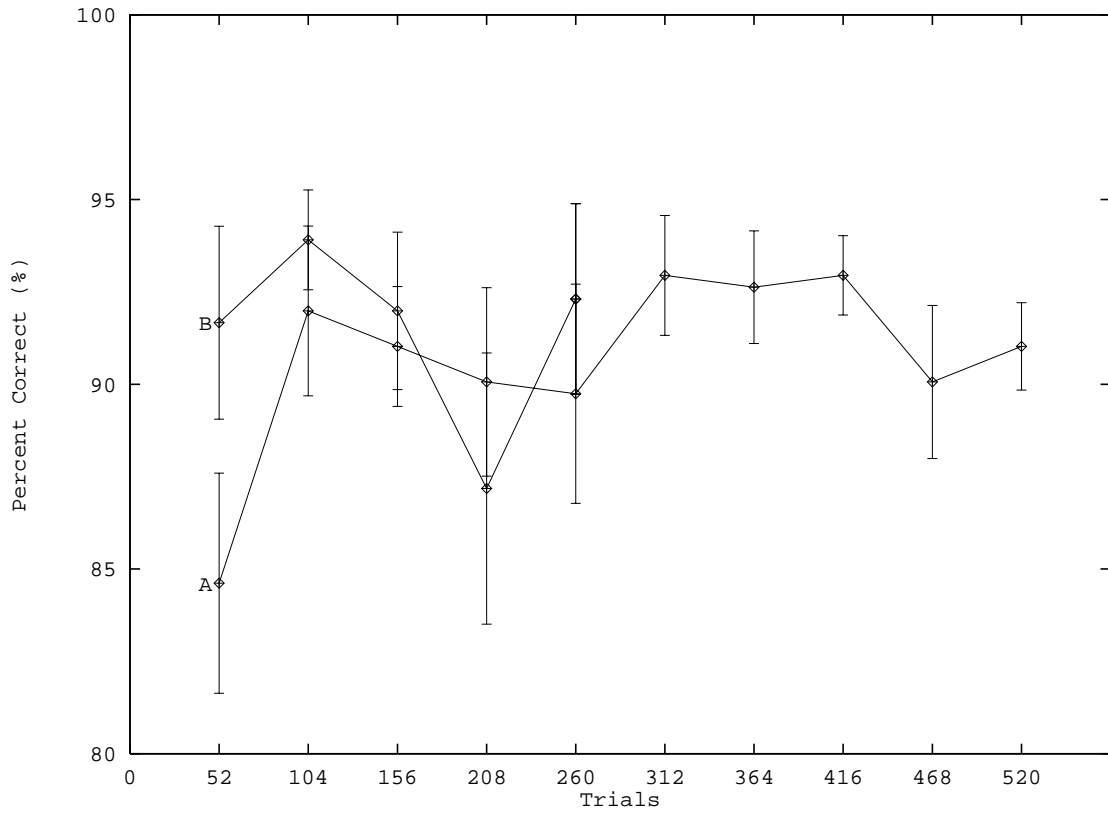


Figure 4: Average percent correct as a function of the trials from the six subjects.

Each datum point is the average of 52 trials from each subject, A or B respectively.

The error bar is  $\pm 1$  standard error.

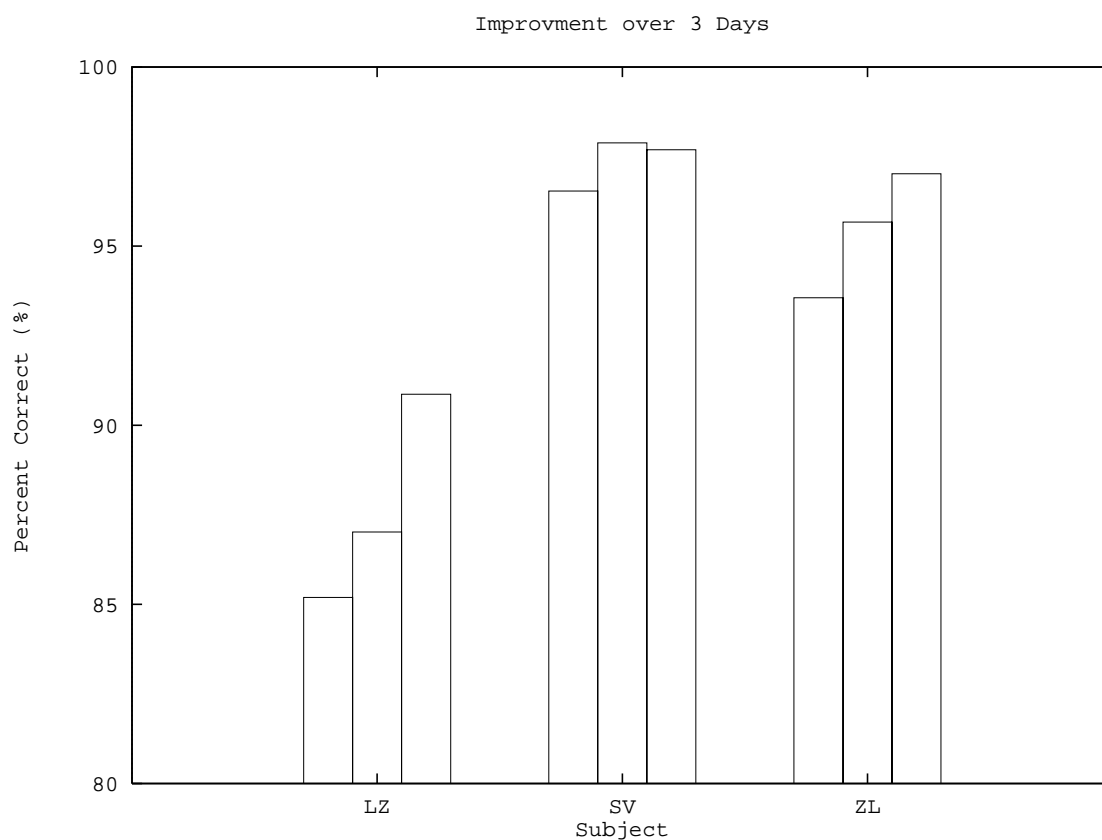


Figure 5: Discrimination scores of the three subjects who completed the task in three consecutive days, 780 trials/day per subject. Subject LZ was unaware of the experimental purpose, Subject SV was, and Subject ZL is the first author. The improvement was significant:  $F(2, 4) = 10.27, p < 0.027$ .

## 4 Discussion

We have presented a novel paradigm to re-address the study of perceptual learning. Our results indicated that a transfer occurred from one stimulus condition to another, when both conditions were interleaved in the stimulus ensemble. The evidence of a positive transfer does not necessarily mean that perceptual learning was stimulus independent, it suggested rather that the stimulus specificity was constrained by the statistical properties of the stimulus ensemble. Therefore, when the experimental conditions were appropriate, a transfer was evidenced — an ecologically reasonable constraint not emphasized by previous perceptual learning studies (but see [7, 8, 9]). Although the result was obtained in a case study of motion direction discrimination, it is our belief that it implies to a great variety of perceptual learning in general.

An immediate question following our case study is what is being learned. One possibility is that subjects have learned a general, stimulus direction independent strategy that learning would transfer to any other directions. Another equally interesting possibility is that whatever being learned was still stimulus specific, only this time specific to both A and B, but not to any other directions.

Perhaps an ever more interesting question is whether transfer can occur between two very different tasks, e.g., one motion direction discrimination, the other auditory tone discrimination. Although we have so far used “transfer” in the positive sense, a negative “transfer”, or interference, is also possible, which may amount to a limited attentional resource.

We chose in this study the motion directions in  $A$  and  $B$  to be opposite, by following Ball & Sekuler (1987), where no transfer is found for motion direction discrimination to the opposite directions. However, neurons that are tuned to opposite motion directions are balanced. If the eyes are extensively exposed to moving stimuli in one direction, motion in the opposite direction will be perceived when eyes thereafter look at static scenes (the so called “waterfall” effect). In this light, directions of motion, which are perpendicular to and independent of (i.e., no transfer) each other should be best to address the issue of transfer of motion learning, and the fact that no transfer is found between two opposite motion directions deserve further investigation.

Finally, in our “ $A-A-B A-A-B \dots$ ” case study, the temporal frequencies of  $A$  and  $B$  sequences were different. Although it seemed not very likely, a control is needed to determine if this temporal difference caused the differential performance between  $A$  and  $B$  conditions. Likewise, we can address stimulus specificity in temporal sequence: suppose a Vernier task is learned within a certain range of orientations, with the orientation of the stimulus in one trial different from the previous one by a certain angle. Now after an extensive training, the same set of stimuli is tested with a different temporal correlation, namely the orientation of the stimulus in one trial is different from the previous one by a yet another angle. The question is: does a transfer occur in this situation? This and the rest of the questions will be addressed in the future.

ACKNOWLEDGEMENT

Thanks to W. Bialek, I. Cox, D. Jacobs, D. Kersten, D. Knill, L. Maloney, P. Mamassian, J. Oliensis, R. de Ruyter, R. Shapley, and V. Sundareswaran for helpful discussions. LV was supported by the NIH-NEI grant EYRO1-07861, McDonnell-Pew grant in Cognitive Science T89-01245-017, and by a contract from ONR, Neural Science Division—N00014-93-1-0381.

## References

- [1] M Fahle and S Edelman. Long-term learning in Vernier acuity: effects of stimulus orientation, range and of feedback. *Vision Research*, 33(3):397–412, 1993.
- [2] CD Gilbert. Neuronal dynamics and perceptual learning. *Current Biology*, 4:627–629, 1994.
- [3] VS Ramachandran and O Braddick. Orientation-specific learning in stereopsis. *Perception*, 2:371–376, 1976.
- [4] A Fiorentini and N Berardi. Learning in grating waveform discrimination: specificity for orientation and spatial frequency. *Vision Research*, 21:1149–1158, 1981.
- [5] K Ball and R Sekuler. Direction-specific improvement in motion discrimination. *Vision Research*, 27(6):953–965, 1987.
- [6] AJ O’Toole and D Kersten. Learning to see random-dot stereograms. *Perception*, 21:227–243, 1992.
- [7] M Ahissar and S Hochstein. Attentional control of early perceptual learning. *Proceedings of the National Academy of Science, U.S.A.*, 90:5718–5722, 1993.



- [8] PG Schyns and GL Murphy. *The Psychology of Learning and Motivation*, chapter The ontogeny of part representations in object concepts, pages 305–347. Academic Press, San Diego, CA, 1994.
- [9] L Shiu and H Pashler. Improvement in line orientation discrimination is retinally local but dependent on cognitive set. *Perception and Psychophysics*, 52(2):582–588, 1992.