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Short communication

Simultaneous learning of motion discrimination in two directions

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Abstract

We take issue with theories about the direction specificity in perceptual learning of motion discrimination. Trials of motion discrimination in two opposite directions were interleaved in uneven proportions (2:1). Human subjects improved *faster* in the direction with less frequent trials, indicating that learning transferred from the more frequent to the less frequent direction. © 1998 Elsevier Science B.V.

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Psychophysical studies have amply demonstrated that in a broad range of perceptual tasks, human subjects' performance improves with practice. An intriguing characteristic of this improvement is that it is stimulus specific. That is, subjects' improved performance under one specific stimulus attribute does not transfer to a significantly different value of that attribute. For example, learning in discriminating a vertical vernier stimulus does not transfer to discriminating a horizontal one [10,3]; learning in stereo discrimination in one orientation of stimulus line elements does not transfer to another orientation [11,9]; learning in waveform discrimination in one orientation and spatial frequency does not transfer to a different orientation or spatial frequency [4]; and finally, learning in direction discrimination of random dot motion in one direction does not transfer to another direction [1,2,12].

While these and other perceptual learning studies found stimulus specificity (see Refs. [5,6] for reviews), one naturally wonders about what role, if any, the training paradigm plays in restricting the learning to the specifically trained stimuli. For instance, it is conceivable that subjects during training only needed to learn the task under the specific attribute of the stimulus, and did not need to generalize to other attribute values. The question we are asking is whether stimulus specific experimental design could have contributed to the stimulus specific perceptual learning.

To address this question, we employed a paradigm of simultaneous learning, with an interleaved stimulus sequence A–A–B, A–A–B, ..., where A and B were different stimulus attributes. Should learning be stimulus specific, we would expect that learning in A and B would be independent, hence the *rates* of improvement for A and B should be identical. If, however, the learning is not stimulus specific, but transfers between the two attributes A and B, we would expect that more improvement occurs in condition B than in condition A, because B is lagging behind A in the learning sequence. More specifically, after $3n$ trials ($2n$ A and n B trials), if learning transfers from A to B, then the amount of improvement for the n B trials should be greater than for the first n A trials.

We used a random dot global motion display whose direction of motion was the average over the whole stimuli. To ensure that only the experimental stimulus was visible, a tube, whose inside was painted black, abutted the computer screen. The length of the tube and the viewing distance were both 90 cm long. Each motion stimulus consisted of 100 dots, each 1.5′ arc wide, on a black background. The subject looked at the display binocularly. The motion stimulus consisted of 10 frames, each lasting 44.7 ms. From one frame to the next, all the dots were re-plotted by adding independent velocity noise to each dot. The direction of a dot was sampled from a Gaussian distribution (mean = global motion direction, standard de-

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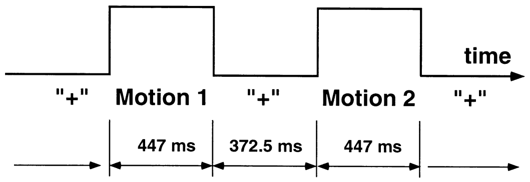

Fig. 1. The schematic of the experimental procedure for one trial: fixation mark '+,' the first motion, fixation, the second motion, and the fixation. The subject was to decide whether the two stimuli moved in the same or different directions. Feedback was provided.

viation $(\sigma_1) = 5°$). The speed of each dot was 3.8′ arc plus the absolute value of a random number from a Gaussian distribution (mean = 0, $\sigma_2 = 1.5'$ arc). The stimuli were displayed on a Macintosh Centris 650s monitor in a circular aperture 8° in diameter. These experimental parameters were chosen in pilot studies so that the task was not too difficult and, at the same time, there was sufficient room for improvement.

The sequence of the trials followed the pattern of *A–A–B*, *A–A–B*, · · · . In each trial, two consecutive motion stimuli were presented, whose global directions were either identical or differed by 30°. In an *A* trial, the two directions were 135° and 165°. In a *B* trial, they were the opposite, i.e., 315° and 345°. We used opposite motion directions because previous studies found that learning in one direction transferred least to its opposite direction [1,2]. The *A*, *B* directions were counterbalanced across subjects.

The subjects' task was to decide in each trial whether the two stimuli moved in the *same* or *different* directions. They were instructed to respond as fast and as accurately as possible. Fig. 1 shows one trial in the following sequence: the first motion, the fixation mark, the second motion, and the fixation mark. The subject responded by pressing one of two keys to indicate whether the two motion directions were the same or different. Feedback for incorrect responses was provided by a computer beep. This completed one trial, and the next started automatically.

Author Z.L. and five naive subjects (five men, one woman, 20–30 years of age) participated in the experiment. All subjects were right-handed, with normal or corrected to normal vision, and used their right hands to respond. Each subject took a total of 780 trials that lasted for about 30 min. The subject was dark adapted and took 20 practice trials (with the same feedback) before the experiment started.

Each subject's discrimination index d' was calculated for the first 260 *A* trials (A_1), all the 260 *B* trials (B), and the second 260 *A* trials (A_2) (Fig. 2). [2] Every subject's d' for *B* was higher than for A_1. This difference was statistically significant ($t(5) = 2.26$, $p < 0.05$, two-tailed), suggesting that the amount of improvement during the same number of trials was greater for *B* than for *A*. This indicates a transfer from *A* to *B*, because the *rate* of improvement for *B* was higher than for *A*.

The key manipulation of our study in this paper is the paradigm of interleaved simultaneous learning, with *unequal* proportions of the two stimuli. The idea is that with unequal number of trials of two different stimuli intermixed, the 'minority' (B) should have a faster learning *rate* as long as learning transfers between the two directions. The null hypothesis is that learning is stimulus specific, so that no learning transfers between the two, and their learning rates should be identical (since the stimuli are of the same difficulty).

The outcome of no transfer is predicted by the classic study of motion discrimination in which learning is direction specific [1,2,12]. These studies further postulate that, since learning is motion direction specific, the underlying neural substrate responsible for learning is at the middle temporal area (MT) where neurons are motion direction selective. In this paper we took a different approach: instead of asking 'where has learning occurred?', we focused on characterizing conditions under which learning is stimulus specific. More specifically, we asked whether the task context constrains such specificity. In our simultaneous learning task, the result suggested that learning transferred, when it was beneficial for the visual system to generalize what was learned between two opposite directions. In other words, when learning one general direction of motion, the visual system may not need to generalize to other directions. When two directions are being learned, the visual system may transfer what is learned between the two directions whenever possible. We take caution and

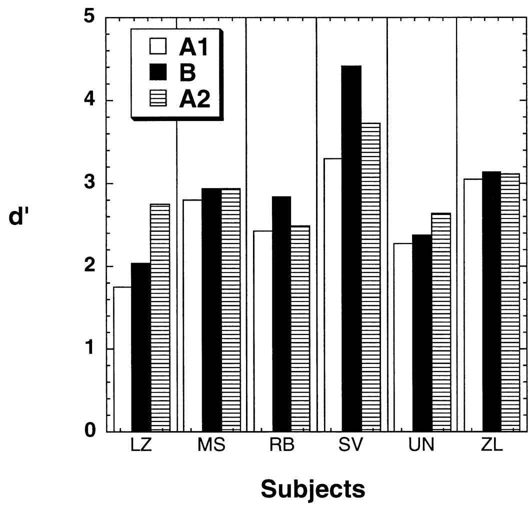

Fig. 2. The discrimination index d' for each subject. 'A_1' represents the first 260 trials of the *A* condition, and 'B' all the 260 *B* trials. The second 260 trials of the *A* condition 'A_2' are also included for comparison. Every subject's d' for *B* is greater than for A_1.

[2] It is not entirely clear why Subjects R.B. and S.V. had a larger d' for *B* than for A_2. We speculate about two possibilities. (1) The difference was due to noise, as data in perceptual learning are typically noisy both between and within subjects. (2) Learning in motion discrimination for opposite directions is not always perfectly symmetric, which we have found in other studies as well [7,8].

note that the A, B directions in this study were opposite to each other, therefore our results finding transfer between them may or may not generalize to other motion directions. After all, the visual system's motion analysis has a direction opponent organization. We speculate, however, that our results are not limited to opposite motion directions, for two reasons. (1) The classic study in Ref. [1] found no transfer whatsoever to opposite directions. In fact, this was the singly most important reason that we chose opposite directions in this study. (2) In other studies [7,8], generalization of perceptual learning was found between orthogonal directions. With this caution in mind, we suggest that perceptual learning in motion discrimination generalizes to other directions as long as the experimental task is appropriate. Studies in perceptual learning should consider both the nature of the stimuli and the nature of the task.

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