Transfer in motion perceptual learning depends on the difficulty of the training task

Xiaoxiao Wang
School of Life Sciences,
University of Science and Technology of China,
Hefei, China

Yifeng Zhou
School of Life Sciences,
University of Science and Technology of China,
Hefei, China

Zili Liu
Department of Psychology,
University of California Los Angeles,
Los Angeles, CA, USA

One hypothesis in visual perceptual learning is that the amount of transfer depends on the difficulty of the training and transfer tasks (Ahissar & Hochstein, 1997; Liu, 1995, 1999). Jeter, Dosher, Petrov, and Lu (2009), using an orientation discrimination task, challenged this hypothesis by arguing that the amount of transfer depends only on the transfer task but not on the training task. Here we show in a motion direction discrimination task that the amount of transfer indeed depends on the difficulty of the training task. Specifically, participants were first trained with either 4° or 8° direction discrimination along one average direction. Their transfer performance was then tested along an average direction 90° away from the trained direction. A variety of transfer measures consistently demonstrated that transfer performance depended on whether the participants were trained on 4° or 8° directional difference. The results contradicted the prediction that transfer was independent of the training task difficulty.

Introduction

Visual perceptual learning is defined as the visual system's capability to improve signal detection, discrimination, or identification in optical stimuli via practice (Epstein, 1967; Fahle & Poggio, 2002; Gibson, 1969). For example, in a motion perceptual learning task, two motion stimuli were shown (Figure 1) (Ball & Sekuler, 1982, 1987). In each stimulus, random dots moved along a single direction. From the first stimulus to the second, the motion direction changed either 0° or 3°. Participants decided whether the two directions were the same or not. The average of these two directions was held constant and was defined as the training direction. Ball and Sekuler (1982, 1987) found that participants substantially improved this direction discrimination through training. They also found that the improvement could not transfer to an untrained average direction that was 90° or more from the trained direction.

Until the mid-1990s, it was believed that humans could improve in almost any visual perceptual task but could not transfer the learning from the trained stimulus attribute to a new attribute, e.g., from the trained direction to a new direction (Fahle, 1997; Fiorentini & Berardi, 1981; Gilbert, 1994; Karni & Sagi, 1991; O'Toole & Kersten, 1992; Ramachandran & Braddick, 1976). Two studies in the late 1990s, however, challenged the notion that perceptual learning could not transfer (Ahissar & Hochstein, 1997; Liu, 1995) (see also Gibbs, 1951 and Lordahl & Archer, 1958). These studies indicated that when task difficulty was reduced, learning could transfer to other stimulus attributes. Specifically, in a motion direction discrimination task (Figure 1), Liu (1995, 1999) enlarged the directional difference from 4° to 8° and found that learning transferred to untrained directions. Ahissar and Hochstein (1997), in a visual search task with oriented bars, manipulated either the possible locations of the target bar or the relative orientation of the target bar with respect to the background bars. In both cases, they found that training with an easier task transferred when the orientations of the target and background bars were swapped.

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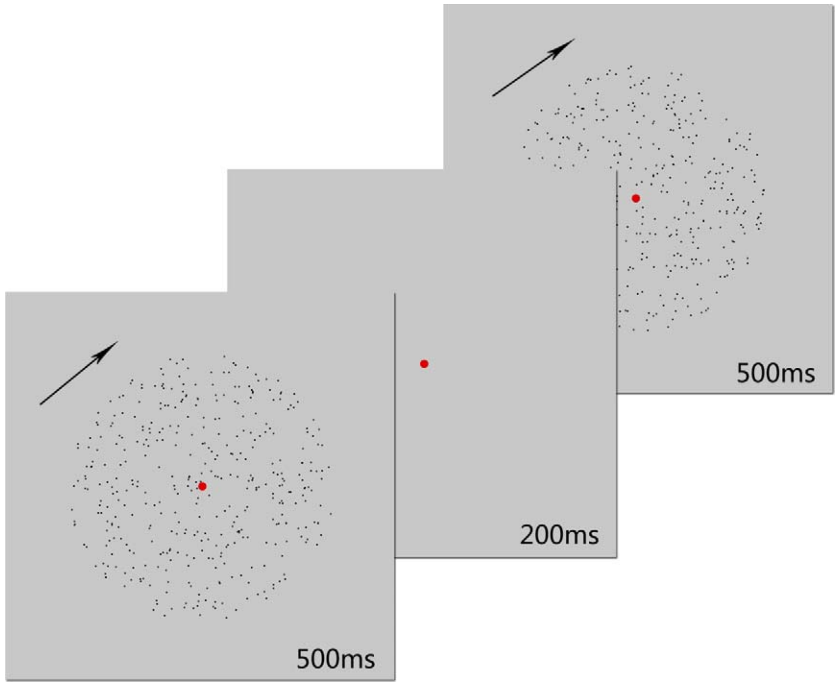

Figure 1. Schematic illustration of a motion direction discrimination trial. The circular aperture remained stationary while the dots inside moved in a single direction in each stimulus. The participant fixated the central disk and decided whether the motion directions of the two stimuli were the same or different.

More recently, however, this hypothesis that transfer depends on the task difficulty of training has been challenged. Jeter, Dosher, Petrov, and Lu (2009) used an orientation discrimination task to argue that performance of a transfer task depended only on the angular size of the orientation difference in the transfer task, but not on the angular size in the training task. Petrov (2009) also argued that transfer of learning in motion direction discrimination depended only on the angular size of the directional difference in the transfer task, but not on the directional difference in the training task. The aim of the current study was to test whether performance in a transfer task is independent of the difficulty of the training task in motion discrimination learning. Our chosen task was adequate not only because Petrov (2009) used the same task, but also because Jeter et al. (2009) claimed that their results applied to perceptual learning in general and were not restricted to orientation discrimination. To anticipate, our results consistently indicated that transfer performance depended on how the participants were trained. Our results therefore contradict Petrov (2009) and the generality of Jeter et al. (2009).

Experiment

Stimuli and task

The stimuli and task were similar to those used in Ball and Sekuler (1982, 1987), Liu (1995, 1999), and Liu and Weinshall (2000), except that the dots were darker than the background. Specifically, 400 dots were uniformly and randomly distributed within a circular aperture of 8° in diameter (262 pixels) (Figure 1). In each of the two stimuli, all dots moved along a single direction, with a speed of 10°/s. The duration of each stimulus was 500 ms, and the interstimulus interval was 200 ms. The motion directions of the two stimuli were either the same or different. When they were different, the difference was either $\pm 4°$ or $\pm 8°$. As an example, the first and second stimulus directions were randomly and independently sampled from the following two directions: 44° and 36°. The participant fixated a central red disk and decided whether the two directions were the same or different. On each trial feedback was provided by a computer beep.

Each dot was 0.09° in size (a 3 × 3 pixel square), with a luminance of 0.0 cd/m^2. The central red fixation disk had a diameter of 0.5° in visual angle (16 pixels) and a luminance of 5.6 cd/m^2. The background luminance was 22.0 cd/m^2.

Two average motion directions, 40° and 130°, were selected that were orthogonal to each other but asymmetric about the vertical axis. The trainees were paired such that trainees in each pair shared the same gender and experimental schedule. One trainee in the pair was randomly assigned to train with 4° direction discrimination and the other with 8° direction discrimination. The experimental procedure was as follows.

1) Pretraining measurement: The performance of all trainees was first measured along the transfer direction, with 12° direction discrimination in the first day that served as practice, 8° in the second day, and 4° in the third day.
2) Training: There were seven daily training sessions. One trainee in a pair was randomly assigned to train with 4° discrimination, the other in the same pair with 8° discrimination.
3) Transfer measurement: One daily session on each of the 4° and 8° discrimination along the transfer direction was measured.
4) Repeating (2)–(3) three more times.

Participants

Sixteen students from the University of Science and Technology of China, Hefei, participated.

Apparatus

Two computer monitors were used. Both were 17-in Sony Multiscan G220 monitors. The resolutions were 1024 × 768 pixels, and the refresh rates were 100 Hz. The participants viewed the stimuli binocularly from a chin rest. The viewing distance was 60 cm. The Experiment used the MatLab software (Mathworks, Inc.) and psychophysics toolbox (Brainard, 1997; Pelli, 1997).

Results

All eight pairs of trainees completed the first three rounds of training and transfer measurement (Figure 2, top), whereas six out of these eight pairs also completed the additional fourth round (Figure 2, bottom). In the Appendix, data from every individual trainee are shown.

Our focus in the hypothesis testing was whether the transfer performance was dependent on training. Specifically, we asked whether there was any interaction effect in the following 2 × 2 analysis of variance (ANOVA): Training (4° vs. 8°) × Transfer (4° vs. 8°). To anticipate, using a variety of measures, we found that the transfer performance was consistently dependent on whether training was 4° or 8° discrimination. Specifically, for 8° transfer discrimination, the 8° trainees discriminated better than their 4° counterparts. The opposite was true for 4° transfer discrimination. The detailed analyses are as follows.

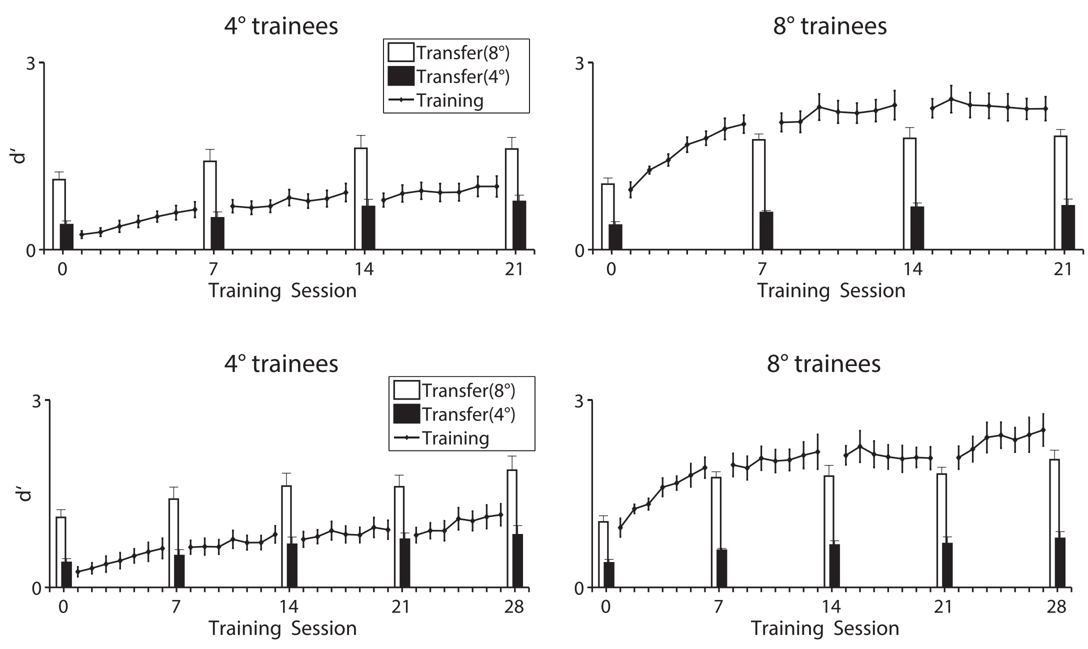

Figure 2. Top row: training and transfer measurement of all 16 trainees in the first three rounds. Bottom row: the complete four rounds of training and transfer measurement for six of the eight pairs of trainees. The error bars are standard errors of the mean between subjects.

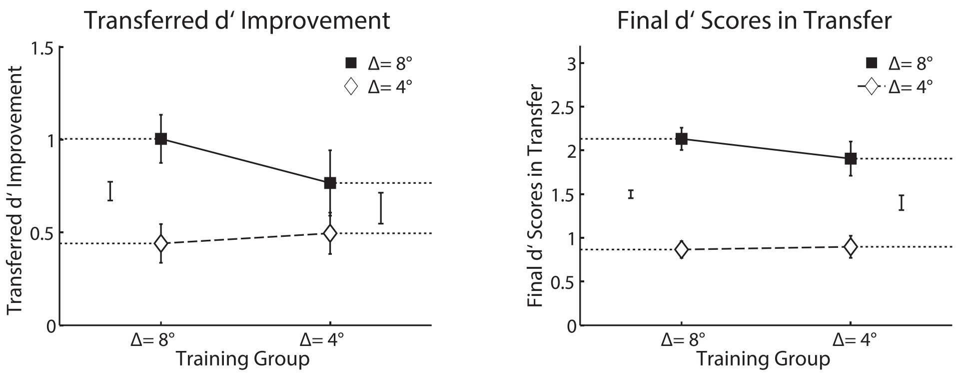

Figure 3. Amount of transfer in directional difference $\Delta = 4°$ and $\Delta = 8°$ discrimination for the 4° and 8° training groups. As the dependent measure, the amount of d' improvement in transfer was used in the left panel, and the final d' in transfer was used in the right panel. The interaction within each panel was significant, indicating that transfer depended on training. The error bars on the four data points in each panel represent between-subjects standard errors. The within-subject standard errors for the 8° training group (left most in each panel) and for the 4° training group (right most) are also shown.

Although the trainees were paired, the pairing was primarily to ensure that the two training groups were balanced in training schedule, the training motion directions, and trainee genders. Such pairing however helped little in terms of reducing individual differences, which are typically large in motion perceptual learning. We therefore conducted an ANOVA with 16 individual, rather than 8 pairs of, subjects. (Otherwise, ANOVA gave rise to slightly larger p values, due to reduced degrees of freedom from 14 to 7.) A two-way ANOVA was performed with training (4° vs. 8°) and transfer (4° vs. 8°) as the main factors. The dependent variable was the amount of d' improvement along the transfer direction from the first to last measurement. The main effect of training was not significant $F(1, 14) < 1$. The main effect of testing was highly significant, $F(1, 14) = 73.29$, $p \ll 0.001$, not surprisingly, since 8° discriminating was easier than 4°. Importantly, the interaction was significant, $F(1, 14) = 9.00$, $p = 0.01$. This means that transfer was dependent on the training difficulty (Figure 3). Similar results were obtained if the last d' measurement in transfer, rather than d' improvement, was used. The interaction was significant, $F(1, 14) = 7.19$, $p < 0.02$.

We then looked at another way of transfer measurement, normalized improvement, defined as (final d' – pretraining d')/(pretraining d') in the transfer task. The interaction effect was not significant, $F(1, 14) < 1$. Upon a closer look, however, the large variance in the data was mainly due to a single trainee, YNN. YNN's pretraining 4° discrimination d' was only 0.26, giving rise to a normalized improvement larger than anybody else's (Figure 4). After removing this data point, we found that the interaction became significant, $F(1, 13) = 7.39$, $p < 0.02$.

Next, we looked at all d' scores throughout the Experiment. Each trainee had four or five d' scores for the 4° transfer discrimination, from which a linear slope was obtained. A linear slope for the 8° transfer discrimination was similarly obtained for each trainee. A similar 2 × 2 ANOVA was performed using these slope data. The interaction was again significant, $F(1, 14) = 9.12$, $p < 0.01$. The slope of the 8° transfer performance for the 8° trainees was numerically greater than for the 4° trainees (0.034 vs. 0.028). The slope of the 4° transfer performance was numerically greater for the 4° trainees than for the 8° trainees (0.021 vs. 0.017) (Figure 5).

We then correlated the transfer slopes with the training slopes. Each trainee contributed two transfer slopes (on 4° and 8° discriminations) and one training slope (either on 4° or 8° discrimination). The data are shown in Figure 6. Each of the four correlations was statistically significant ($p < 0.05$). These results indicate that performance in the transfer direction depended on training performance. In other words, it appears incorrect to characterize the transfer performance as independent of the training. In order to further verify this, we randomly scrambled the pairing between the transfer and training slopes, such that each new pair of data were from two trainees, rather than from only one trainee. After each scrambling, we computed a new correlation for each panel in Figure 6. We repeated this procedure 10,000 times and obtained four distributions of the correlation coefficients. We asked whether the mean of each distribution was reliably different from zero. In all four cases, no mean correlation coefficient was significantly different from zero ($t < 1$). This result indicated that a trainee's transfer performance depended on their training performance.

Also interestingly, the correlation coefficient between the 8° transfer discrimination with 8° training was higher (0.78, the top-left panel) than that between the 4° transfer discrimination with 8° training (0.72, the top-

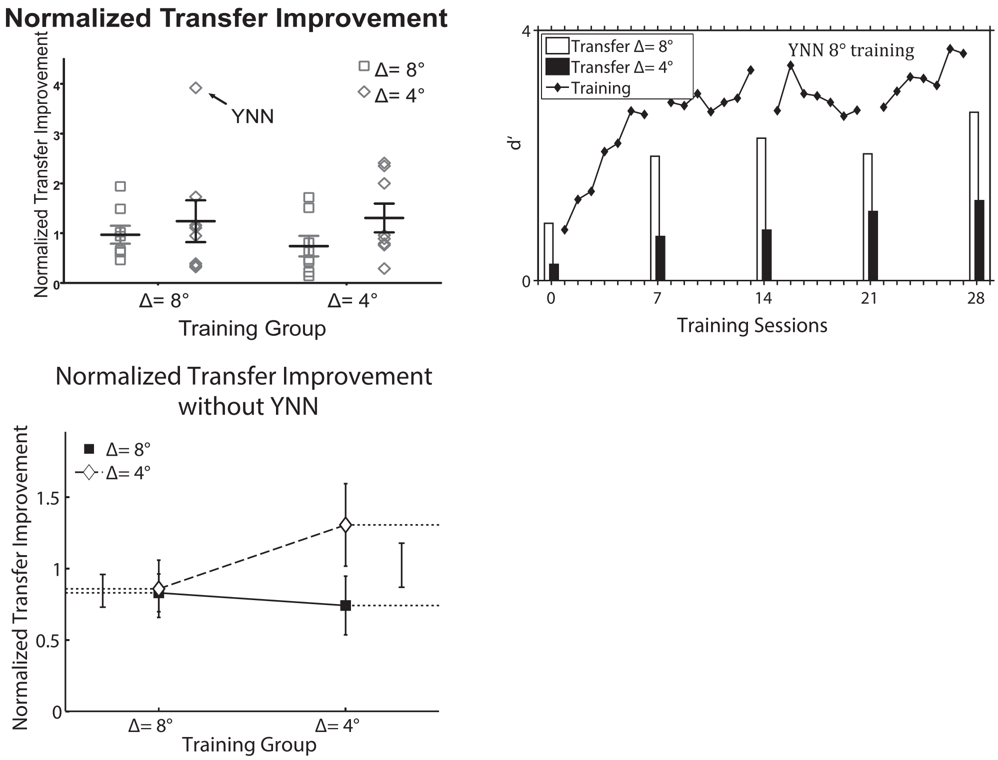

Figure 4. Top left: scatter plot of all 16 trainees' normalized transfer scores, defined as (final d' − pretraining d')/(pretraining d') in transfer measurement. The interaction effect was not significant, mainly due to an outlier trainee's data in the top right panel. Bottom left: the 2 × 2 interaction plotted similarly as in other figures, without the outlier trainee. The interaction was now significant.

right panel). The correlation coefficient between the 4° transfer discrimination with 4° training was also higher (0.91, the bottom-right panel) than that between the 8° transfer discrimination with 4° training (0.84, the bottom-left panel). In order to access the reliability of these two differences, we performed bootstrapping analysis for each of the two training groups (10,000 samples with replacement) (Efron & Tibshirani, 1993). In both cases, the difference was significant ($p < 0.001$, $t > 25$). This was supportive evidence that transfer was dependent on training.

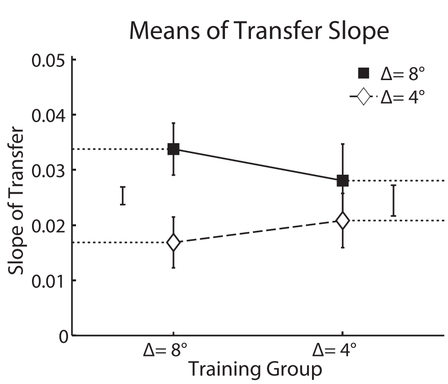

Figure 5. The slopes of discrimination sensitivity index d' along the transfer direction for the 8° and 4° discrimination, and for the 8° and 4° training groups, respectively.

Finally, we tested whether the transfer performance depended on task difficulty of training from the following perspective. If the transfer performance only depended on the similarity between the transfer and training tasks, regardless of task difficulty, then the 4° and 8° discrimination performance should be symmetric with each other. Namely, the absolute difference in performance between 4° and 8° discrimination for the 4° trainees should be the same as for the 8° trainees. We conducted such tests, which were different from the interaction effects above because the differences were all in absolute values. In Figure 3 left, $t(14) = 3.04$, $p < 0.01$. In Figure 3 right, $t(14) = 2.68$, $p = 0.018$. In Figure 4 bottom, $t(13) = 1.84$, $p = 0.08$. In Figure 5, $t(14) = 3.03$, $p < 0.01$. These results rejected the symmetry hypothesis and suggested that the pattern of the results was not completely due to the similarity between training and transfer tasks but that transfer performance depended on the difficulty of the training task.

Discussion

We found in this study that after training along one average motion direction, participants' sensitivity in motion direction discrimination along an untrained average direction depended on what training stimuli

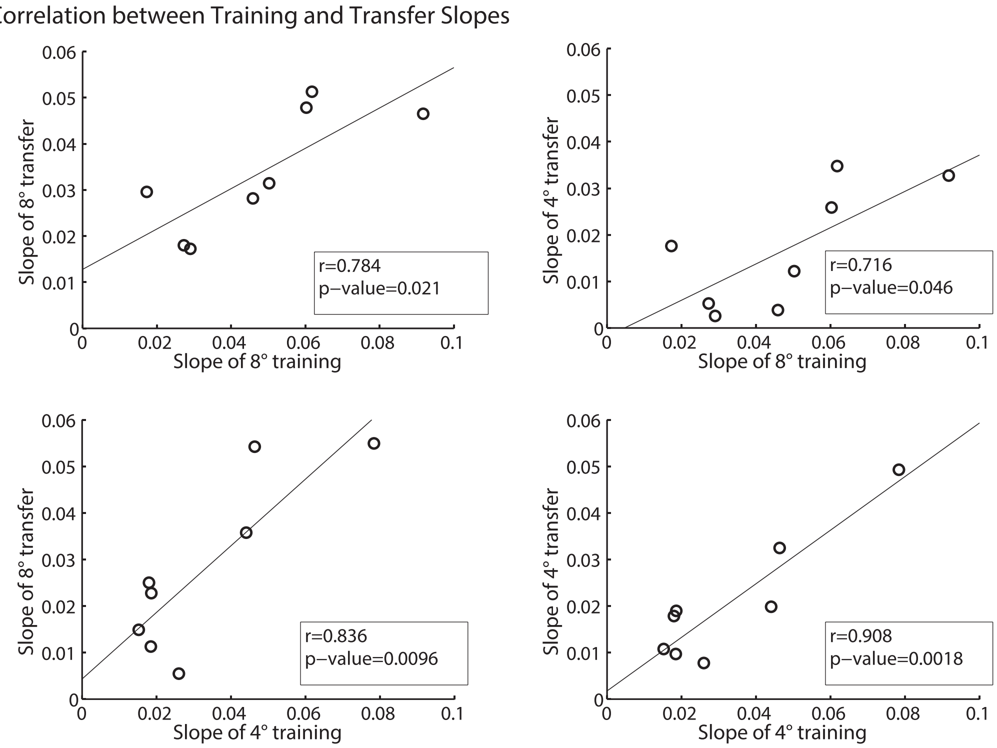

Figure 6. Correlation between the training *d′* slope and transfer *d′* slope for the 8° training group (top row) and 4° training group (bottom row) and for the 8° transfer discrimination (left column) and 4° transfer discrimination (right column). In each of the four panels, each trainee contributed one data point. All four correlations were statistically significant.

were used. Specifically, no matter if the transfer performance was measured in *d′* increment from pre- to post-training, or in post-training *d′*, or in the slope of *d′* increment throughout the course of transfer testing, the 8° trainees outperformed the 4° trainees in 8° transfer discrimination. The 4° trainees outperformed the 8° trainees in 4° transfer discrimination. This dependence on training stimuli was statistically significant in all cases.

How might one understand these results? In other words, why were the results above sensible? Although these results measured different aspects of transfer performance, they were all consistent with the notion of stimulus specificity. Namely, the transfer (defined in each of the four cases above) was more when the transfer stimulus was more similar to the training stimulus. This pattern of stimulus specificity was consistent with a large body of conventional perceptual learning studies (see for a review Fahle, 2005). We further demonstrated that this pattern of results could not be completely accounted for by the similarity between training and transfer tasks. Transfer performance indeed depended on the difficulty of the training task.

We should point out that this stimulus specificity was not very strong in that not all individual pairwise comparisons were statistically significant, although the interactions were always significant. This may be in part due to the fact that 4° and 8° discriminations were asymmetric to each other, in the sense that 4° discrimination was harder. In other words, the 4° trainees went through a more demanding training regimen. There is evidence in the memory literature that harder training eventually leads to more accurate memory recall (Bjork, 1994). Although we did not find overall better discrimination sensitivities for the 4° than 8° trainees, our transfer measurement always followed immediately after training. It remains an open question whether in the long term the 4° training group could show a discrimination advantage.

A second reason that the stimulus specific transfer results were relatively weak was that the numerical difference between 4° and 8° was subtle. Due in part to this subtle difference, we found that the training *d′* improvement slope was always positively correlated with the transfer *d′* improvement slope. This positive correlation was true regardless if the training or transfer was 4° or 8° discrimination. Interestingly, stimulus specificity was also present in that the correlation coefficient was always higher, with statistical significance, when the discrimination angles for training and transfer matched (both were 4° or both were 8°) than mismatched.

The fact that both 4° and 8° transfer slopes were correlated with the training slope should *not* be considered as evidence of transfer being independent of training. On the contrary, this was strong evidence that transfer performance depended on the particular participant's training performance. This was shown when the pairing between a trainee's transfer slope and the *same* trainee's training slope was broken up, such that one trainee's transfer slope was randomly paired with another trainee's training slope. After this random scrambling, the correlation disappeared. In summary, all behavioral measures in the present study consistently showed that transfer performance depended on the task difficulty of training.

We now discuss the implications of our results above in the context of the orientation discrimination study by Jeter et al. (2009). Jeter et al. (p. 1) argued that the amount of transfer was dependent only on the precision of the transfer task "regardless of the precision of initial training." The precision of training in our task was the angular size of motion directional change, either 4° or 8°. This statement of "regardless of the precision of initial training" apparently meant that, in our case, one of the two angles (4° or 8°) had to be used in training. It seems unlikely that any precision would do, because it had already been demonstrated otherwise in the literature. Specifically, in Rubin, Nakayama, and Shapley (1997), the easier inducers that facilitated harder thin–fat shape discrimination shared the same stimulus size as the harder inducers. When the easier inducers became larger, no facilitation could be found. Therefore, the training stimuli had to be the same size as the transfer stimuli, and easier inducers facilitated more than harder inducers in the subsequent transfer test using the harder inducers. In other words, the training stimuli mattered. Likewise, in the "Eureka" effect in Ahissar and Hochstein (1997), the transfer specifically depended on the long presentation (30 s) of a single stimulus. The same stimulus that was presented for 0.05 s in each of the 600 trials could not enable the transfer. Here, it is not straightforward to use the term *precision*. Nevertheless, one can think about precision in this case as follows. The high-precision task (or small angle orientation discrimination) has a lower stimulus signal–noise ratio (SNR) than does a low-precision task (large angle orientation discrimination). Consequently, when a stimulus was presented with a long duration, the associated uncertainty was lower, and hence its SNR was higher.

In Liu and Weinshall (2000), both the training and transfer tasks had to be directional discrimination tasks for the transfer to take place. Otherwise, when there was no training or when the training used a similar stimulus but different task, little transfer was found. Liu and Weinshall (2000) further demonstrated that training along a second average motion direction was nearly twice as fast as along the first direction. Therefore, these results suggested that it mattered whether or not the training task was motion discrimination for motion discrimination transfer. What Liu and Weinshall (2000) did not show was whether or not the training task difficulty mattered for the transfer.

Jeter et al. (2009) and Petrov (2009) argued that the training task difficulty or precision did not matter for the amount of transfer. We demonstrated here to the contrary in motion direction discrimination learning. It is unclear why we and Petrov (2009) obtained opposite results. Both of the studies used 4° and 8° direction discriminations. Petrov (2009) used filtered texture patterns as stimuli and each motion was shown for 400 ms, whereas we used random dots and each motion was shown for 500 ms. It is not obvious whether these differences were responsible for the different results. Perhaps a more likely cause of the difference was that participants in Petrov (2009) were trained with four sessions, whereas our participants were trained with at least 21 sessions. The fact that our participants were tested with the transfer performance three or four times was probably not crucial, however. In Ball and Sekuler (1987), for example, participants' transfer performance was measured in Sessions 1, 4, and 7, whereas Sessions 2, 3, 5, and 6 were training sessions. Ball and Sekuler (1987) found little transfer for their 3° direction discrimination. It remains therefore an open question as to what the causes were that gave rise to different results in Petrov (2009) and our current study.

Our results, however, did not directly contradict Jeter et al. (2009) since our task was motion discrimination whereas theirs was orientation discrimination. One of Jeter et al.'s contributions was to demonstrate that, in orientation discrimination, the training stimuli did not have to be unique. The angular size for orientation discrimination could be in a range where all values gave rise to similar transfer.

Keywords: perceptual learning, motion transfer, difficulty, task precision

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Commercial relationships: none.
Corresponding author: Zili Liu.
Email: zili@psych.ucla.edu.
Address: Department of Psychology, University of California Los Angeles, Los Angeles, CA, USA.

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Appendix: Data from all individual trainees

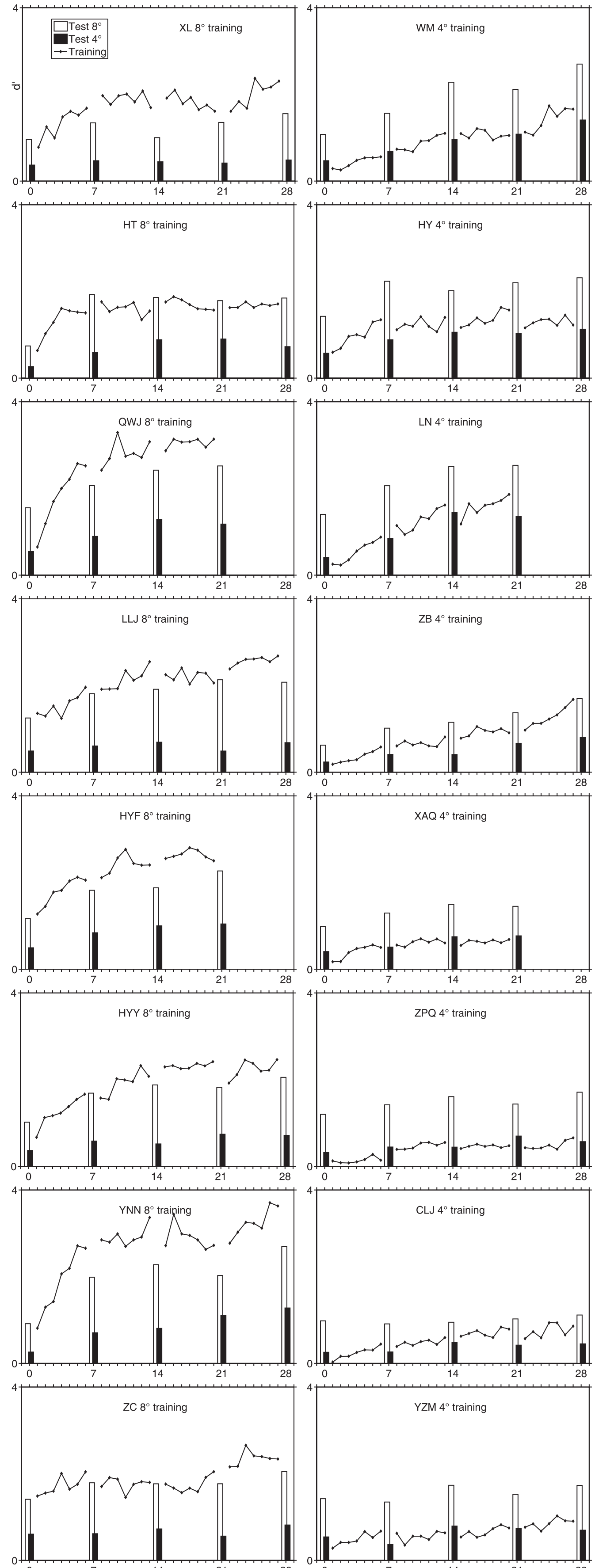

Figure A1. Data from all individual participants. Left: 8° trainees. Right: 4° trainees.