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SPECIAL ISSUE
Perceptual Learning
GUEST EDITORS
Zhong-Lin Lu, Cong Yu, Dov Sagi, Takeo Watanabe, Dennis Levi
REWARD
MECHANISMS GATING LEARNING
LEARNING SIGNALS
ATTENTIONAL SELECTION
High Level Processing
Low Level Processing
WHAT IS LEARNED
TASK IRRELEVANT STIMULUS
TASK RELEVANT STIMULUS
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Editorial

Perceptual learning: Functions, mechanisms, and applications

1. Introduction

Perceptual learning refers to a general class of phenomena related to improved performance as a result of training or practice in perceptual tasks. Perceptual learning is of theoretical significance in illuminating plasticity in adult perceptual systems, and in understanding the limitations in the information processing of the human observer, and how the state of the observer changes with training. Perceptual learning is of practical significance as a potential noninvasive method for the development of perceptual expertise in normal populations and for the amelioration of deficits in challenged populations by training.

2. A brief history of studies on perceptual learning

Historically, the role of learning in perception was vigorously denied by early Gestalt psychologists (e.g., Max Wertheimer). Helmholtz, however, assigned learning an extremely important role in his theories of perception. In 1969, Gibson published the first book on perceptual learning, with the view that perceptual learning is a process of discovering how to transform previously overlooked potentials of sensory stimulation into effective information. A resurgence of research on perceptual learning occurred in the late 1980s and early 1990s, when Dov Sagi and others systematically documented various specificities of perceptual learning and postulated the hypothesis that perceptual learning may occur in early sensory cortical areas. In the last three decades, hundreds of papers on perceptual learning have been published, documenting perceptual learning in all sensory modalities and almost all perceptual tasks. Today, more than 50 laboratories around the world are engaged in research on perceptual learning, using techniques ranging from single-unit recording to human psychophysics and brain imaging.

3. The first International Workshop on Perceptual Learning in Beijing

To bring together active researchers in the field of perceptual learning to share methods and techniques as well as research findings, and to identify the most important issues and new research directions, we initiated a biennial International Workshop on Perceptual Learning. The first workshop, organized by Zhong-Lin Lu (USA), Cong Yu (China), Dov Sagi (Israel), and Takeo Watanabe (USA), was held at Beijing Normal University in Beijing, China, from October 15, 2008 to October 19, 2008. The workshop brought together more than 20 world-class investigators from many complementary disciplines – psychophysics, neurophysiology, functional imaging, computational neuroscience, and perceptual rehabilitation, all contributors to the study of the functions, mechanisms, and applications of perceptual learning. The scientific program included 19 talks:

- Takeo Watanabe: Task-irrelevant learning occurs only when the irrelevant feature is weak.
- Miguel Eckstein: Human vs. optimal Bayesian learner.
- Zhong-Lin Lu, & Barbara A. Dosher: Mechanisms of perceptual learning.
- Dennis M. Levi, Roger W. Li, & Stanley Klein: Prolonged perceptual learning in adult amblyopia: dynamics of template retuning and noise reduction.
- Mike Merzenich: Controlling cortical plasticity.
- Hubert R. Dinse: Perceptual learning through passive stimulation.
- Guoqiang Bi: Dynamics and plasticity of reverberatory activity in small neuronal networks.
- Dov Sagi, & Nitzan Censor: Perceptual learning: the problem of saturation and ways to avoid it.
- Uri Polat: Making perceptual learning practical.
- Aaron Seitz: The role of reward in perceptual learning.
- Michael H. Herzog: Top-down processing in perceptual learning.
- Geoff Ghose: Learning to be fast.
- Wu Li, Valentin Piëch, & Charles D. Gilbert: Visual Cortical Plasticity and Perceptual Learning.
- Yuka Sasaki: Location-specific cortical activation changes during sleep after training for perceptual learning.
- Li Zhaoping: Perceptual learning the recurrent intra-cortical interactions in primary visual cortex.
- Cong Yu, Jun-Yun Zhang, Lu-Qi Xiao, Stanley, A. Klein, & Dennis M. Levi: Significant transfer of perceptual learning across retinal locations and orientations revealed in a double training paradigm.
- Merav Ahissar: Auditory perceptual learning – interplay between low and high-level representations.
- Kazuhisa Shibata, Shin Ishii, Noriko Yamagishi, Mitsuo Kawato: Boosting perceptual learning by fake feedbacks.
- Stanley Klein: Whorfian Hypothesis.

Participants of the workshop not only reported the latest advances in their research, but also engaged in lively discussions and friendly debates both in the scheduled discussion period after each talk and during many social events. We all agreed that the first workshop was extremely successful in fostering exchanges of ideas and multidisciplinary collaborations. A photograph from our trip to the Great Wall of China is reprinted in Fig. 1.

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4. Introductions to papers in the special issue

Following the workshop, we invited all the participants and many other investigators on perceptual learning who could not attend the workshop for various reasons to contribute to a Special Issue of Vision Research on perceptual learning. We received about two-dozen submissions. Because of the large number of manuscripts, the special issue will be published in two volumes. The current issue is the first volume of the Vision Research Special Issue on Perceptual Learning. It consists of the first 11 accepted manuscripts from the submission pool. The second volume will consist of all the other accepted manuscripts.

In the opening article, Levi and Li (2009) provide a critical review and "meta-analysis" of perceptual learning in adults and children with amblyopia, in an attempt to extract principles that might make perceptual learning more effective and efficient in treating amblyopia. One referee believes that the paper should be required reading for all readers interested in amblyopia in general and treatment of amblyopia in particular.

The second paper, by Censor and Sagi (2009), discusses potential issues with over-training that decreases rather than increases perceptual performance. They showed that performance decrements can be prevented by short training periods followed by sleep; and the prevention generalizes across retinal locations. The decrements caused by over-training, on the other hand, are retinal location specific. The authors conclude that there are both local and global components of perceptual learning that are realized in both early and higher cortical areas.

A number of papers have suggested that the hippocampus plays a significant role in consolidation of memory and learning during sleep. To test whether this is the case, Mednick, Makovshi, Cai, and Jiang (2009) have examined how performance of contextual cued learning, known as hippocampus-dependent learning, is changed after an interval of sleep, active wake or quiet rest. Interestingly, no significant performance change was found after any one of the three types of intervals, as compared to before the interval. These results suggest that at least one form of hippocampal learning is not dependent on sleep. On the other hand, previous studies found that sleep plays a significant role in learning of the texture discrimination task (TDT). Thus, the results of the current paper indicate that the role of sleep is not necessarily consistent across different types of learning. It would be interesting to examine whether the role of sleep shown in TDT learning is extended to other types of perceptual learning of primitive visual features.

In adults with normal vision, practice can improve performance on a variety of visual tasks, and this learning can be quite specific (to the trained task, orientation, eye, etc.). The specificity of perceptual learning poses some interesting difficulties. If the improvement following practice was solely limited to the trained stimulus, condition and task, then PL would have very limited (if any) practical utility. One paper (Polat, 2009) describes the use of a structured perceptual learning method that has been applied to amblyopia, myopia and presbyopia. They report that training improved contrast sensitivity and diminished the lateral suppression when it existed (amblyopia), and most importantly that the improvement transferred to untrained functions such as visual acuity and to improved processing speed of target detection as well as reaction time (in presbyopia). Thus, perceptual learning may provide a practical method to improve visual functions in individuals with impaired or blurred vision.

In a second study Polat, Ma-Naim, and Spierer (2009) asked whether perceptual learning may improve the vision of children after conventional patching treatment has failed. They carried out a prospective clinical pilot study in children who were non-compliant with patching or in whom patching had failed despite good compliance. They report an average improvement in visual acuity of ≈1.5 Snellen lines and improved the contrast sensitivity, which reached the normal range after treatment. Thus, perceptual learning can be successfully used to treat children with amblyopia even after the conventional treatment of patching fails.

While the role of feedback in perceptual learning is a fascinating subject, it has yet to be entirely clarified. Shibata, Yamagishi, Ishii, and Kawato (2009) found that fake block feedback indicating a larger performance improvement than the true improvement facilitates perceptual learning to a greater degree than the genuine block feedback informing precise performance results. Such a facilitation effect of fake feedback is explained and even predicted by a computational model that assumes unsupervised learning in the visual system and Bayesian learning rate control in higher cognitive systems. These findings suggest that feedback can potentially boost or optimize perceptual learning.

Aberg and Herzog (2009) report some interesting observations on the effects of stimulus temporal order (multi-stimulus practice in blocked, sequentially interleaving, and randomly interleaving "roving" trials) on perceptual learning. They first present the finding that learning is found in roving but not alternating regimes of a 2-line bisection task, which runs in direct contradiction to recent results reported by a number of previous studies (Adini, Wilkonsky, Haspel, Tsodyks, & Sagi, 2004; Kuai, Zhang, Klein, Levi, & Yu, 2005; Otto, Herzog, Fahle, & Zhaoping, 2006; Yu, Klein, & Levi, 2004; Zhang et al., 2008). They concluded through a post hoc statistical analysis that initial task performance can predict a large degree of the variability in learning found in perceptual learning tasks. The study raised some important issues on the many potential contributing factors to perceptual learning, which often go unnoted in other reports of perceptual learning.

Choi, Seitz, and Watanabe (2009) examined the effects of attention on task-irrelevant perceptual learning. They found that task-irrelevant perceptual learning occurs only when exogenous attention is directed away from the task-irrelevant task, not when subjects attend to the task-irrelevant task. They conclude that task-irrelevant perceptual learning occurs primarily because depletion of spatial attention disabled the visual system to suppress the unwanted signal. The study provides a key conceptual framework to understand many related studies on task-irrelevant perceptual learning.

Seitz and Watanabe (2009) provide an extended review of the phenomenon of task-irrelevant perceptual learning, emphasizing the role of gating and reward. The authors incorporate the concepts of gating and attention into their account of task-irrelevant learning and discuss the different roles attributed to these processes.

Neuronal processes involved in learning take time to stabilize and to be consolidated. For the texture segmentation task this stabilization may take a few hours. Here, Yotsumoto, Chang, Watanabe, and Sasaki (2009) find interference between learning of two texture stimuli that are practiced consecutively with a short temporal gap, but not when practiced during the same time (using the roving method). This shows that learning of two stimuli can be acquired in parallel but their consolidation is susceptible to interference. Most importantly, two stimuli that share the same learning process (i.e. learning transfers from one to another) do not interfere while two stimuli that require separate learning processes do interfere. Based on these results, Yotsumoto et al. suggest that interference takes place in early sensory brain-regions, pointing to primary visual cortex as a possible anatomical site for the consolidation of texture learning.

Hussain, Sekuler, and Bennett (2009), using face and texture recognition tasks, find that perceptual learning does not necessarily require many practice trials. Efficient learning can be observed even with stimuli exposed only once in a training session. Hussain

Fig. 1.

et al. show that learning in their tasks depends on the number of trials practiced but not on the distribution of trials across sessions. The results show a perfect memory across training sessions (days) for the learning effects gained within a daily session.

5. Concluding remarks

As we finish editing this first volume of the Vision Research Special Issue on Perceptual Learning, planning of the second International Workshop on Perceptual Learning, to be held in Israel in late 2010, is well under its way. We strongly believe that bringing together scientists from many complementary disciplines – psychophysics, neurophysiology, functional imaging, computational neuroscience, and perceptual rehabilitation – is extremely important for advancing our knowledge and understanding of perceptual learning. We thank those who attended the first workshop, whose presentations and discussions made it such a success, and all the contributors to this special issue. We hope that the special issue will provide an excellent introduction to the current state of research on perceptual learning.

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References

Aberg, K. C., & Herzog, M. H. (2009). Interleaving bisection stimuli – randomly or in sequence – does not disrupt perceptual learning, it just makes it more difficult. *Vision Research, 49*, 2591–2598.

Adini, Y., Wilkonsky, A., Haspel, R., Tsodyks, M., & Sagi, D. (2004). Perceptual learning in contrast discrimination: The effect of contrast uncertainty. *Journal of Vision, 4*, 993–1005.

Censor, N., & Sagi, D. (2009). Global resistance to local perceptual adaptation in texture discrimination. *Vision Research, 49*, 2550–2556.

Choi, H., Seitz, A. R., & Watanabe, T. (2009). When attention interrupts learning: Inhibitory effects of attention on task-irrelevant perceptual learning. *Vision Research, 49*, 2586–2590.

Gibson, E. J. (1969). *Principles of perceptual leaning and development*. New York: Appleton-Century-Croft.

Hussain, Z., Sekuler, A. B., & Bennett, P. J. (2009). How much practice is needed to produce perceptual learning? *Vision Research, 49*, 2624–2634.

Kuai, S.-G., Zhang, J.-Y., Klein, S., Levi, D. M., & Yu, C. (2005). The essential role of stimulus temporal patterning in enabling perceptual learning. *Nature Neuroscience, 8*, 1497–1499.

Levi, D. M., & Li, R. W. (2009). Perceptual Learning as a potential treatment for amblyopia: A mini-review. *Vision Research, 49*, 2535–2549.

Mednick, S. C., Makovshi, T., Cai, D. J., & Jiang, Y. V. (2009). Sleep and rest facilitate implicit memory in a visual search task. *Vision Research, 49*, 2557–2565.

Otto, T. U., Herzog, M. H., Fahle, M., & Zhaoping, L. (2006). Perceptual learning with spatial uncertainties. *Vision Research, 46*, 3223–3233.

Polat, U. (2009). Making perceptual learning practical to improve visual functions. *Vision Research, 49*, 2566–2573.

Polat, U., Ma-Naim, T., & Spierer, A. (2009). Treatment of children with amblyopia by perceptual learning. *Vision Research, 49*, 2599–2603.

Seitz, A. R., & Watanabe, T. (2009). The phenomenon of task-irrelevant perceptual learning. *Vision Research, 49*, 2604–2610.

Shibata, K., Yamagishi, N., Ishii, S., & Kawato, M. (2009). Boosting perceptual learning by fake feedback. *Vision Research, 49*, 2574–2585.

Yotsumoto, Y., Chang, L., Watanabe, T., & Sasaki, Y. (2009). Interference and feature specificity in visual perceptual learning. *Vision Research, 49*, 2611–2623.

Yu, C., Klein, S. A., & Levi, D. M. (2004). Perceptual learning in contrast discrimination and the (minimal) role of context. *Journal of Vision, 4*, 169–182.

Zhang, J.-Y., Kuai, S.-G., Xiao, L.-Q., Klein, S. A., Levi, D. M., & Yu, C. (2008). Stimulus coding rules for perceptual learning. *PLoS Biology, 6*, 1651–1660.

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