Visual Perceptual Learning

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Synonyms

Sensory plasticity; Sensory learning; Visual plasticity; Perceptual Improvement

Definition

Practice or training in perceptual tasks improves the quality of perceptual performance, often by a substantial amount. This improvement is called *perceptual learning*, in contrast with learning in the cognitive or motor domains. Research on perceptual learning is of theoretical significance in illuminating plasticity in adult perceptual systems, and in understanding the limitations in the information processing of human observers. It is of practical significance as a potential method for the development of perceptual expertise in normal populations and for the non-invasive amelioration of deficits in challenged populations by training.

Theoretical Background

Historically, the role of learning in perception was vigorously denied by early Gestalt psychologists such as Max Wertheimer. Helmholtz, however, assigned learning an extremely important role in his theories of perception (Helmholtz, 1911). In 1967, Eleanor J. 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 (Gibson, 1967). 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 put forward the hypothesis that perceptual learning may occur in early sensory cortical areas (Karni & Sagi, 1991). Since then, perceptual learning in adult human observers has been documented in a wide range of perceptual tasks (Fahle & Poggio, 2002).

The most distinctive finding in perceptual learning is that some of what is learned is specific to stimulus or task factors such as retinal location (Karni & Sagi, 1991), spatial frequency (Fiorentini & Berardi, 1980), orientation (Ball & Sekuler, 1982), or background texture (Ahissar & Hochstein, 1996). Perceptual learning that is highly specific to retinal location and stimulus has been claimed to reflect neural plasticity in basic visual processing mechanisms (Karni & Sagi, 1991).

Recent studies have investigated mechanisms of perceptual learning, i.e., what is learned during perceptual learning, using psychophysics (Dosher & Lu, 1998; 1999; Gold, Bennett & Sekuler, 1999; Saarinen & Levi, 1995), neurophysiology (Crist, Li & Gilbert, 2001; Ghose, Yang & Maunsell, 2002; Schoups, Vogels, Qian & Orban, 2001), brain imaging (Schiltz, Bodart, Dubois, Dejardin, Michel, Roucoux, Crommelinck & Orban, 1999; Schwartz, Maquet & Frith, 2002), and patients (Fahle & Daum, 2002; Xu, Lu, Wang, Dosher, Zhou, Yang, Zhang & Zhou, 2010).

In psychophysical studies, Dosher and Lu (1998) introduced a theoretical framework and an external noise plus training paradigm to analyze how perceptual inefficiencies improve over the course of perceptual learning. Perceptual inefficiencies are attributed to three limitations in perceptual processes (Lu & Dosher, 2008): an imperfect perceptual template, internal additive noise, and multiplicative noise. Systematic measurements of human performance as a function of both the amount of external noise added to the signal stimulus and the length of training received by the observers make it possible to distinguish three mechanisms of perceptual learning: perceptual template retuning, stimulus enhancement, and contrast-gain control reduction. It has been consistently found that two independent mechanisms, stimulus enhancement and external noise exclusion, support perceptual learning in a range of tasks (Dosher & Lu, 1998; 1999; 2005; 2007; Lu, Chu & Dosher, 2006; Lu & Dosher, 2004).

Practice-induced neuronal plasticity has been documented in auditory (Metherate & Weinberger, 1990; Weinberger, Javid & Lepan, 1993) and somato-sensory cortices (Jenkins, Merzenich, Ochs, Allard & Guic-Robles, 1990; Recanzone, Merzenich & Schreiner, 1992), and in some visual functional Magnetic Resonance Imaging (fMRI) studies (Schiltz et al., 1999; Schwartz et al., 2002; Vaina, Belliveau, des Roziers & Zeffiro, 1998). Evidence for practice-induced neuronal plasticity in early visual cortical areas is however modest (Crist et al., 2001; Ghose, Yang & Maunsell, 2002; Schoups, Vogels, Qian & Orban, 2001; Yang & Maunsell, 2004), although neurons in the primary visual cortex (V1) may exhibit task specific tuning (Li, Piech & Gilbert, 2004) that seem to reflect selection of task-relevant stimulus features for a particular task rather than persistent cross-task neuronal tuning changes. Law and Gold (2008) conclude, "…[our] results suggest that the perceptual improvements corresponded to an increasingly selective readout of highly sensitive medial temporal (MT) neurons by a decision process, represented in lateral intraparietal (LIP), that instructed the behavioral response." On the other hand, some recent evidence might suggest greater plasticity in early visual areas occurs in non-primates (Hua, Bao, Huang, Wang, Xu, Zhou & Lu, 2010).

Important Scientific Research and Open Questions

One major open question is whether perceptual learning reflects representation enhancement in early sensory areas or reweighting of sensory representation in the decision process. Petrov, Dosher, and Lu (2005) introduced a task analysis framework to evaluate the diagnostic value of experimental designs for discriminating reweighting and representational enhancement in perceptual learning. A systematic review of the literature suggests that the two potential forms of plasticity – reweighting versus representational change – make similar predictions about specificity in most of the existing studies that had previously been cited as evidence for representational enhancement. Based on the results from the task analysis and neurophysiology, Petrov et al (2005; 2006) implemented the reweighting hypothesis outlined in Dosher and Lu (1998) in a multi-channel Augmented Hebbian Reweighting Model (AHRM). The AHRM has been very successful in modeling a wide range of phenomena in perceptual learning.

Another important topic in perceptual learning concerns the role of feedback. A complex pattern of empirical results on the role of feedback in perceptual learning has emerged - see Petrov, Dosher, & Lu (2006) and Dosher & Lu (2009) for reviews. Whereas most perceptual learning studies employed trial-by-trial feedback, several studies documented significant perceptual learning with block, partial, or even no feedback, and no perceptual learning with false, random, manipulated block, and reversed feedback (Herzog & Fahle, 1997). Shibata, Yamagishi, Ishii & Kawato (2009) showed that arbitrary block-feedback facilitated perceptual learning if it is more positive than the observer's actual performance. At high-training accuracies, feedback is not necessary (Liu, Lu & Dosher, 2008), and significant learning was found in low-training accuracy trials when they were mixed with high-accuracy trials (Liu, Lu & Dosher, 2009; Petrov, Dosher & Lu, 2006). Liu, Lu & Dosher (2010) conducted a computational analysis of the complex pattern of empirical results on the role of feedback with the AHRM (Petrov, Dosher & Lu, 2005). The simulation results are both qualitatively and quantitatively consistent with the data reported in the literature.

A number of recent papers re-examined specificity of perceptual learning and found that a number of factors in the training procedures, some of which were not obviously related to specificity or transfer of learning, determine the degree of specificity, including task precision (Jeter, Dosher, Petrov & Lu, 2009), task difficulty (Ahissar & Hochstein, 1997), number of trials (Censor & Sagi, 2009), and training schedule (Xiao, Zhang, Wang, Klein, Levi & Yu, 2008). Xiao et al (2008) developed a novel double-training paradigm that employed conventional feature training (e.g., contrast) at one location, and additional training with an irrelevant feature/task (e.g., orientation) at a second location, either simultaneously or at a different time. They showed that this additional location training enabled a complete transfer of feature learning (e.g., contrast) to the second location. Understanding factors that determine specificity/transfer of perceptual learning may elucidate the functional architecture of perceptual learning.

Cross-References

Adaptation and learning
Animal perceptual learning
Computational learning theory

Connectionist theories of learning
Cross-modal learning
Expertise and learning
Feedback and learning
Hebb, Donald O. (1904 – 1985)
Insight in Perceptual Learning
Learning receptive fields
Learning to learn
Mechanisms of learning
Modes of learning
Multi-channel learning
Perception and learning
Perceptual learning
Perceptual processing and learning
Perceptual similarity (and learning)
Sensitization (in non-associative learning)
Signal-detection (models)
Speech perception and learning
Supervised learning
Task difficulty and learning
Task sequencing and learning
Task-irrelevant perceptual learning
Unsupervised learning

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