What is new in perceptual learning?

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What is new in perceptual learning? In the early days of research, specificity was *the* hallmark of perceptual learning; that is, improvements following training were limited to the trained stimulus features. For example, training with a stimulus improves performance for this stimulus but not for the same stimulus when rotated by 90° (Ball & Sekuler, 1987; Spang, Grimsen, Herzog, & Fahle, 2010). Because of this specificity, learning was thought to be mediated by neural changes at the early stages of vision. In the last decade, many procedures were discovered in which transfer occurs from trained to untrained conditions under certain conditions. The location of learning is now often thought to occur in higher stage of vision and decision-making. This special issue shows how the field has progressed along these lines.

The role of transfer

One method enabling transfer is the so-called double training procedure (Xiao et al., 2008). For example, intermingled training at two locations with Verniers of orthogonal orientations leads to improved performances at both locations and for both orientations. Here, Cong, Wang, Yu, and Zhang (2016) show that similar results do not occur when, during training, different tasks rather than locations are intermingled (Training-Plus-Exposure), provoking the question of how and when exactly transfer occurs.

Double training is only one method to induce transfer in perceptual learning. Cueing exogenous attention can also lead to transfer across locations. In a study by Donovan and Carrasco (2015), participants were trained with Gabors that appeared either in the upper or lower part of the left visual field. When the upcoming location was cued during training, participants showed similar improvements for the corresponding untrained locations in the right visual field.

Transfer also occurs when the read-out rules of stimuli are similar in two conditions. Observers estimated the orientation of a Gabor patch relative to a reference line. When the line orientation varied from trial to trial, transfer occurred to an untrained condition with a varying reference line. No transfer occurred to a non-varying line condition (Green, Kattner, Siegel, Kersten, & Schrater, 2015).

While the above findings are impressive, it remains an open issue when exactly transfer occurs. This is particularly evident in the study of Kiorpes and Mangal (2015), where *amblyopic* macaque monkeys were trained in a motion direction discrimination task. All four monkeys improved performance. Interestingly, monkeys showed transfer to at least one other paradigm but this transfer was inconsistent across monkeys. Talluri, Hung, Seitz, and Seriès (2015) propose a model explaining why transfer may be specific for participants. The key idea is that in difficult tasks, synaptic changes occur in the projections from early visual areas to decision units, thus, leading to specificity, whereas for easier tasks, changes occur between later stages and the decision unit enabling transfer. Because task difficulty is subjective, incorporating weights for individual confidence levels improves model performance.

Based on clinical examples, Levi, Shaked, Tadin, and Huxlin (2015) showed that with a standard learning

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paradigm, training with moving dots improves contrast sensitivity in orientation and direction discrimination of drifting sine wave gratings, which were not part of the training. This result questions the specificity of perceptual learning in general. However, effects are small and reminiscent of findings in many studies on perceptual learning, where there is some, usually non-significant, transfer to untrained stimuli.

Two papers by Liang, Zhou, Fahle, and Liu (2015a, b) failed to replicate transfer in double training. In the first study (Liang et al., 2015a), a double training paradigm was administered in a long-term experiment, without finding transfer. In the second study, Liang et al. (2015b) could not replicate the findings from Zhang and Yang (2014) using the same number of participants ($n = 6$) and same methods (for a reply, see Zhang & Yu, 2016). It is important to note that sample sizes in both studies ($n = 6$) are rather small and thus the difference in the studies may be due to undersampling and a lack of power.

Jacoby and Ahissar (2015), in an opinion paper, criticize methodological shortcomings in many perceptual learning studies. In particular, they emphasize the importance of an active control group. They, claim that control groups often do not take part in any training or in less challenging tasks compared to the participants in the experimental group. As in working memory studies, improvements for the experimental group may be due to placebo-like effects or procedural learning. Moreover, authors show that correlations between the improvement on the trained and the transfer tasks cannot be taken as evidence for transfer.

Mechanisms

Where does perceptual learning occur? On which level of visual processing is learning operating? The last decade has seen a shift from early visual areas towards later processing stages. Recently, Pourtois, Rauss, Vuilleumier, and Schwartz (2008) and Bao, Yang, Rios, He, and Engel (2011) claimed that perceptual learning modulates the C1 component in the EEG, which was taken as evidence that perceptual learning occurs at early visual areas. In this issue, Zhang, Li, Song, and Yu (2015) show that the C1 component can be modulated by top-down processing and thus may not be indicative for early visual learning, reopening the debate. In the time frequency domain, Bays, Visscher, Dantec, and Seitz (2015) show that perceptual learning increases alpha activity in the EEG during prestimulus period, which may indicate that the task becomes more automatic. Interestingly, prestimulus alpha power gradually increased when perceptual bias decreased (Nikolaev, Gepshtein, & van Leeuwen, 2016), indicating a complex role of alpha band activity in perceptual learning.

Modeling in the last decade has provided powerful architectures, in which learning occurs mainly from the mapping of sensory evidence to decision making (Petrov, Dosher, & Lu, 2005). Improvements of performance can be due to both increases of sensitivity and adjusting response bias (Herzog, Ewald, Hermens, & Fahle, 2006). Disentangling the two is a computational challenge. Here, Liu, Dosher, and Lu (2015) show that the augmented Hebbian reweighting model can flexibly cope with various feedback conditions, such as trial by trial and block feedback, and that it disentangles bias and sensitivity learning by computations located at the decision stage.

A very general challenge for modeling perceptual learning is presented by Grzeczkowski, Tartaglia, Mast, and Herzog (2015). In 4,160 trials, the very same bisection stimulus was presented without an offset (i.e., the central line was always presented in the middle). Reminiscent of previous findings in the auditory system (Amitay, Irwin, & Moore, 2006), training with such identical stimuli improved the ability to discriminate left versus right offsets. This result contradicts predictions of all neural network models, which predict that learning occurs only when stimuli vary from trial to trial.

To better understand the mechanisms of perceptual learning, Yashar, Chen, and Carrasco (2015) investigated learning when the target is crowded by flanking elements. Learning strongly improved mainly by learning to ignore the flankers. Hence, target perception can improve in other ways than just fine tuning of target related mechanisms.

Clinical and applied

How can we avoid car accidents? Could perceptual learning help? Yes, it can. Deloss, Bian, Watanabe, and Andersen (2015) show that humans can improve perception on whether an approaching car will hit them or pass (tested with approaching spheres on computer screens). Importantly, learning occurred only when stimuli were near threshold.

There is good news also from ageing and clinical research. In general, vision deteriorates with age and even faster with disease, such as macular degeneration. Astle, Blighe, Webb, and McGraw (2015) show that whereas crowded peripheral word identification is worse in older people, perceptual learning brings them on the same level as younger controls who trained with the same number of stimuli. Hence, learning gains of the elderly are higher than of younger people. Also participants with age-related macular degeneration strongly improve performance but do not reach the level of young controls.

The good news continues in the contribution by Yan et al. (2015). Myopic patients improved contrast sensitivity and visual acuity through perceptual learning, mainly due to a reduction of internal noise. The very same results were found in cortically blind people, where training to discriminate motion direction led to internal noise reduction in the blind field (Cavanaugh et al., 2015).

Summary

The current special issue offers a representative view of the current state of the art in perceptual learning including experimental, theoretical, and clinical work. Obviously, the field is progressing more than ever and an exciting future with new twists seems to be just ahead.

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