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Translating Perceptual Learning from the Laboratory to Applications

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Abstract

Human training studies in the laboratory have demonstrated plasticity in brain systems and, in some cases, large improvements in perceptual performance, inspiring a quest to develop training apps and systems. We consider the next steps in the translation from laboratory to clinic and commerce.

Keywords

perceptual learning; vision training systems; clinical applications; optimization

Progress in vision training science

Years of research in perceptual learning on human adults shows substantial performance improvements for simple visual feature discrimination through complex object recognition [1]. Investigations into the mechanisms of perceptual learning in animals and humans revealed plasticity in a cascade of brain systems [2]. These laboratory findings have inspired the development of training applications in clinical populations such as amblyopia and low vision or for perceptual expertise (e.g., [3]). An active marketplace is seeking to develop commercial apps and systems that incorporate vision training technologies [4]. The next steps involve optimizing and extending effective training procedures to different subpopulations, improving generalization, and a proactive approach to regulatory requirements in translating perceptual learning from the laboratory to applications..

Training visual tasks

For more than a century it has been known that intensive practice can lead to specialized perceptual expertise. Examples include the sophisticated palate of the wine expert, the classification of texture, grade, and length of the wool on the trading floor, the sensitivity to resonance and timbre of the virtuoso musician, and the visual sensitivity of the x-ray radiologist. Indeed, psychology laboratory work more than a century ago demonstrated improvements in tactile judgments and even accommodation to major distortions of the

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visual world through prisms [5]. More recently, controlled laboratory research has documented significant improvements in performing trained tasks [6]. Effects of perceptual learning have been reported in almost every visual domain, from the detection or recognition of basic features like orientation, spatial frequency, and motion to the recognition of textures, patterns, and objects, illustrating extensive visual plasticity in the human adult. Studies of perceptual learning in monkeys reveal plasticity in cellular responses along the visual pathway [7].

The potential for improving visual performance has generated considerable interest in applying perceptual learning for visual rehabilitation. Previously thought to be treatable during early childhood, amblyopia has recently been targeted for rehabilitative training in adults. Several groups have shown measureable improvements in visual acuity and contrast sensitivity in the amblyopic eye [3]. Vision training has also been applied in low vision populations, where it can help participants develop a stable preferred retinal locus, improve letter and character recognition, and improve reading speed [8]. One commercial app offers vision training to improve vision in presbyopia [9]. There are, however, challenges in translating perceptual learning to improving perception. Below, we consider several of them in turn.

Generalization of trained skills

One of the hallmark findings of perceptual learning is its specificity to the trained task or stimuli [6]. Although the patterns of specificity in different tasks can inform us about the locus of plasticity, specificity can limit the magnitude of the trained benefits for other stimuli and tasks. Future research could be directed to discovering ways to support generalization of learning to other tasks and other contexts of use. Although generalization is a major challenge in vision training [as in cognitive function training, see 10], it should be acknowledged that in certain cases improvements in the trained task(s) can by themselves be very valuable. If you suffer from low vision, you may be pleased to improve your reading with training even if it does not generalize to other forms of perception.

Existing laboratory studies often use relatively simple training tasks and examine performance only on the trained task and possibly a couple transfer tasks. We suggest that research on perceptual learning could include more naturalistic training tasks and an assessment battery that includes a broader range of visual tests from basic visual features to daily visual functions such as reading, driving, or cooking. One possible tactic to achieve generalization is to target training early in the visual system, such as contrast detection, that may feed the cascade of other visual processes; another is to train at a level of visual coding or representation that is widely shared among the desired transfer tasks.

Testing efficacy of training

As we identify promising vision training protocols in the laboratory, the next steps in translation may be assisted by consideration of factors relevant in clinical trials. So, if the goal is to prove the efficacy of the training system, larger subject samples, inclusion of control groups, and careful randomized assignment can all be important (Figure 1). Control groups should be selected and tested in the same way as the active group but without the target intervention or using other comparison interventions. Although in some cases achieving double-blind designs in which the subject is unaware of the treatment group may be difficult—performing thousands of trials of practice over many days without knowing something about the "treatment" is implausible—pre/post assessment and data analysis could be blind to the group assignment.

Finally, better classification of subtypes of the population with visual performance assessment batteries may help identify possible subgroups that could benefit most from training. For example, training that benefits one type of amblyopia, or younger individuals, or individuals with worse initial performance, could motivate future research on the appropriate population.

Regulatory considerations

The translation of vision training into advances in clinical or commercial applications can have important benefits for society and the economy. A training system or app is regulated as a medical device by the FDA when the intended use, as conveyed by "…labeling claims, advertising materials, or oral or written statements by manufacturers or their representatives…" is for "…the diagnosis of disease or other conditions, or the cure, mitigation, treatment, or prevention of disease, or is intended to affect the structure or any function of the body of man, …" and the "…level of regulatory control necessary to assure safety and effectiveness varies based upon the risk the device presents to public health" [11]. To translate a vision training protocol into a commercial product, early consultation with the FDA can guide product development and the commercialization process.

Whether as a clinical trial or in medical device commercialization, the regulatory environments also highlight the question of potential side effects of the proposed procedures. Many of these same issues are managed in basic research, where researchers are required to inform subjects of potential risks and benefits of protocols that have been approved by review boards. In the case of vision training, the intended population can be an important issue. Development of normal visual function depends on early visual experience [12] which implies a higher standard in evaluating any training interventions for unintended consequences in children. Another relevant consideration is the opportunity cost of pursuing a particular training system as compared with other possible activities. The opportunity costs may be economic, or they may simply involve the time and effort involved in training. This raises a different question about the degree to which a vision training system has been optimized for both effectiveness and cost. At the same time, the FDA procedure could be challenging and constrain flexibility in adapting new advances. Some have suggested that the FDA could treat therapeutic gaming products, by analogy to other noninvasive systems such as medical smartphone apps, by issuing guidelines for developers and consumers (e.g., [13]).

Optimizing learning outcomes

Translating perceptual learning from the laboratory into applications provides the motivation and objectives to optimize vision training. We suggest this can be accomplished within the framework of mathematical optimization [14]. The framework requires an explicit objective function specifying the goal of optimization and a generative model that can take specific stimuli and training sequences and predict the impact of training (Figure 2). Research on mechanisms of perceptual learning has produced some potential generative models, e.g., the integrated reweighting theory [15]. Once an experiment is performed to estimate parameters of this quantitative model, it can be used to predict the learning outcome from a large number of potential training protocols, including those with different training stimuli, sequence of training, feedback, and so on, of model tasks. The optimal procedure is the one that generates the best outcome for a stated goal. Such model-based optimization allows the evaluation of many possible training variants that would be simply impossible with empirical research that would be prohibitively time consuming and expensive.

Future development of optimized vision training will involve the effort of researchers from many disciplines. For example, the generative models could be elaborated to incorporate more realistic visual processing modules, to extend the range of visual tasks modeled, and to expand the range of visual outcomes. The specification and validation of visual performance outcome measures will require input from the clinical community, especially if the training is applied to clinical populations. Candidate training protocols will require empirical validation. The joint efforts from vision scientists, computer modelers, physiologists and clinicians will be tremendously important in development.

Concluding Remarks

Many years of research on perceptual learning and some recent applications in clinical populations indicate the potential of incorporating training in enhancement or remediation of specific visual functions. Optimizing vision training for real world applications presents many challenges and opportunities for the basic and clinical research community. Successful procedures in visual perceptual learning could provide signposts for advancements in related areas of cognitive training.

Acknowledgments

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Glossary

Visual perceptual learning

Improved performance in perceptual tasks through training or practice.

Amblyopia

A developmental disorder in spatial vision that cannot be attributed to structural abnormalities nor corrected by lenses.

Preferred retinal locus

An alternative area of the retina chosen as the center of gaze when the fovea is diseased.

Presbyopia

A gradual and progressive loss of the ability of the aging eye to focus on near objects.

Objective function

A function or equation specifying the value of different outcomes that is optimized (maximized) by an optimization procedure.

Generative model

A system that generates predicted outcomes for different interventions.

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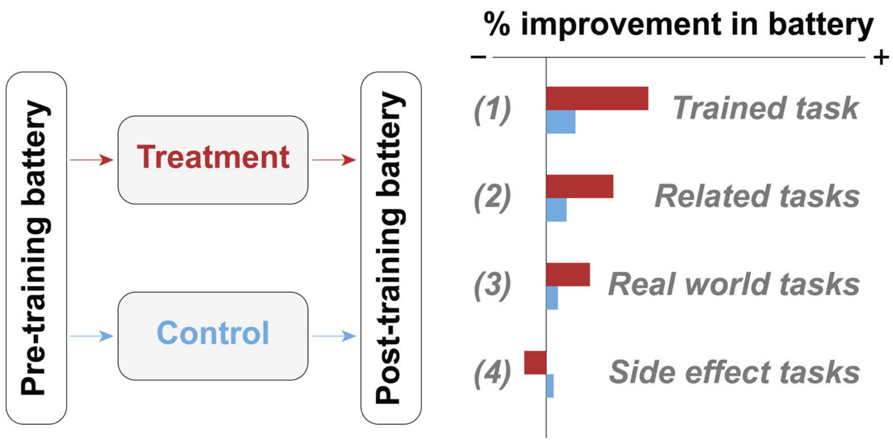

Figure 1.

A broad assessment battery is necessary to evaluate vision training. The effects of treatment are compared with control across several types of tasks, including the trained tasks, related tasks, real-world tasks and potential side effects tasks.

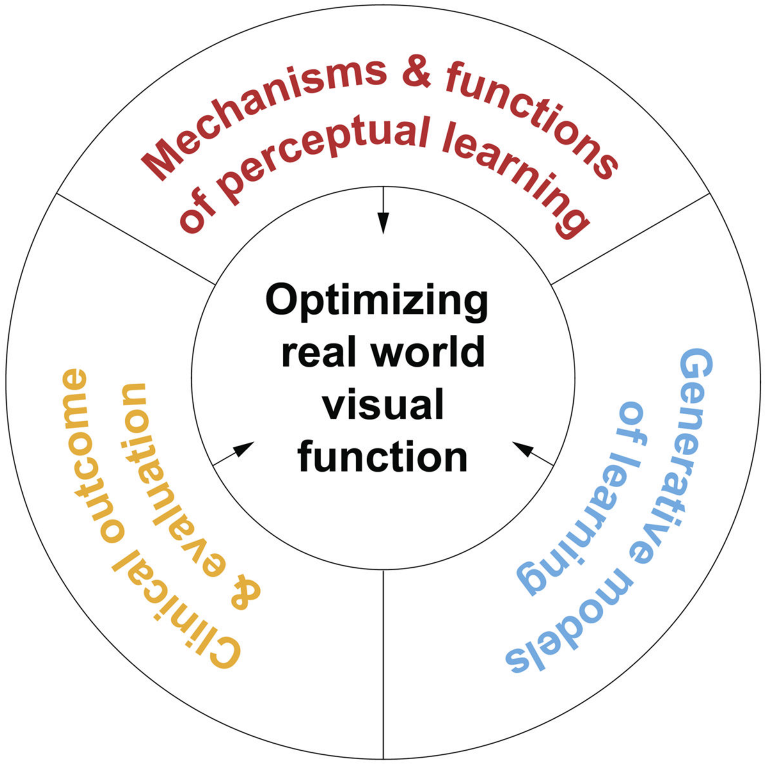

Figure 2.
A three-pronged approach toward optimizing real world visual function. Joint efforts are needed from vision scientists, computer modelers, physiologists and clinicians to understand generative models of learning, mechanisms and functions of perceptual learning, and to evaluate training protocols and clinical outcomes.