Commentary

Auditory Perceptual Learning

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An interesting phenomenon in science is how the discovery of new techniques, findings, or theoretical understanding can produce cyclical waves of interest in a research area. Such is the case for perceptual learning, which is currently enjoying a renaissance following previous periods of excitement, some 50 and 100 years ago (Meyer 1899; Seashore et al. 1908; Gibson 1953). In this issue, Karmarkar and Buonomano (2003) energize this resurgence with exciting work on auditory perceptual learning.

There seem to be two converging reasons for the revival of interest in this field. The first derives from discoveries in neuroscience of plasticity in the mature brain (for review, see Calford 2002). Initially prompted by findings that lesions in the peripheral somatosensory system led to remapping of the lesioned limb or digit in the cortex, this field evolved in several directions, including studies of how intensive, specific training could also lead to remapping in the cortex. The second reason for the current interest in perceptual learning derives from an increased understanding of the nature of learning difficulties, particularly in children. In the mid-1990s, neuroscientists latched on to a stream of research in developmental psychology showing that some children with language-based learning impairments (LLIs), such as dyslexia, had poor visual and auditory temporal processing abilities. Since then, there has been a huge surge of activity (for review, see Ramus 2001) showing that children with LLI have a wider range of difficulties processing sensory stimuli. These difficulties typically involve multiple sensory, cognitive, and motor systems. But most controversial, and potentially most significant from an applied perspective, has been the finding that training based on the principles of perceptual learning can effectively treat these processing problems and the LLI that they are associated with (Merzenich et al. 1996; Tallal et al. 1996; Kujala et al. 2001).

Against this background, Karmarkar and Buonomano (2003) present data on the learning of an auditory interval discrimination task. During training, adult listeners had to decide whether a test pair of tones were separated by a shorter or longer interval than a target pair presented at the onset of a trial block. The frequency of the tones and the target interval were varied between listeners. All listeners were tested on a battery of similar stimuli at both trained and untrained frequencies and target durations before and after 10 d of training. For listeners who learned, the results showed generalization of training across tone frequency but not across target interval. Generalization of training to a tone-duration discrimination task was also observed. This suggested that training for auditory temporal information occurs in centralized brain circuits that are accessed across frequency channels.

One of the goals of Karmarkar and Buonomano's work was to ensure that enhanced performance resulted from improved timing per se, rather than from an enhanced ability to store and/or compare a standard and a comparison stimulus. To achieve this, they allowed the participant to hear the standard several times only at the beginning of a block, and on each trial, participants were presented only with the comparison stimulus. As it seems unlikely that the relatively few presentations of the standard were sufficient to develop a concept of the standard, the authors interpreted the improved performance as indicating that the participants formed a dynamic representation of the time frame, and adjusted this timing based on the feedback from their decisions. However, their results can be interpreted as showing an enhanced ability to store and/or compare stimuli from trial to trial. A strategy of comparing the current interval with the previous one (for which the correct response was known) would have worked well, as trials that were long relative to the standard were also longer than an immediately preceding short trial, and vice versa. Using this strategy, the participant's ability to discriminate successive intervals would be improved by training, but the learning would be confined to intervals around the trained interval, since generalization to other intervals was not observed. This hypothesis could be tested by examining generalization to a standard closer to the trained standard (e.g., one threshold away). Alternatively, trial by trial comparisons could be controlled as an independent variable by use of different presentation methods such as a conventional, two-interval task, or the method of constant stimuli.

This fascinating study addresses several other research themes that are central to an understanding of perceptual learning and its application. A major one is generalization. The authors focused on the implications of the pattern of learning generalization that they observed for the locus of the learning. Thus, learning across frequency suggested that the learning occurred outside of the core auditory pathway,

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where neurons are sharply tuned to tone frequency, in circuits that are dedicated to specific time spans. However, although this idea is appealingly simple, it is unclear why such circuits should necessarily exclude sharply tuned neurons, provided that neurons tuned to a variety of frequencies are included in the circuit. If this were the case, a primary site for the learning may occur at an earlier stage of the auditory pathway than the authors suspect. Generalization is, in addition, crucially important for the applicability of the research. To be effective, for example as a treatment for LLI, learning must generalize from simple acoustic stimuli to more complex, linguistic tokens and from disjointed pairs of sounds to continuous discourse. The results of this study give us some hope that, at least in the auditory system, useful and substantial generalization can occur across stimulus dimensions.

Another intriguing aspect of this work is the issue of cross-modal generalization, not this time of the learning itself, but of the principles of learning. Research into perceptual learning is dominated by studies of vision, and theories of learning are correspondingly based largely on visual data. But the data presented in this work and other recent studies of auditory learning suggest that it may differ qualitatively from visual learning. Examples cited by Karmarkar and Buonomano (2003) include the findings that increasing the task difficulty in visual learning has been associated with decreasing transfer (generalization) of the learning to untrained stimuli, and that at least some types of visual learning are spatially specific to the retinal area trained. In contrast, the transfer of auditory learning can be independent of the task difficulty and, as discussed above, can occur across tone frequencies, the dimension along which the auditory sensory epithelium is mapped. Thus, whereas auditory processing difficulties are increasingly becoming recognized as the main form of sensory impairment in LLI (Ramus et al. 2003), the potential for remediation deriving from auditory training appears to be considerably greater than that deriving from visual training.

Research studies of learning in both hearing and vision usually take great care to distinguish between procedural and perceptual learning. Procedural learning is somewhat vaguely defined, but we take it to mean a full understanding of the rules of the task. It is undoubtedly the case at the outset of learning that most, or all participants have some difficulty remembering and executing the task and that, as a result, they make errors that are not due to the perceptual challenge of the task. Typically, this issue is solved by providing a number of training trials to familiarize the participant with the task, and a larger number of pre-test trials, to measure base-line performance. However, we believe this practice, which is used in the present study, can be misleading. Substantial perceptual learning may occur in the very first trials, as evidenced by the dramatic improvements made early in learning by participants who are, nevertheless, highly experienced psychophysical observers. The pattern of errors shown by many observers in the early trials is also illuminating. Performance often advances as a series of plateau in the learning curve, rather than the multiple-exponential growth of learning that might be predicted from discrete, temporally segregated types of learning. The challenge for future studies is, in our view, to incorporate the likelihood of early perceptual learning into the design of the experiment rather than simply to exclude the early trials from consideration.

Another general, methodological short-coming of most studies of perceptual learning is that they tend to examine highly selected groups of participants, namely, the students of prestigious research universities. There is a close relation between perceptual performance and various indicators of more complex task performance, such as IQ (Deary 1995). Consequently, student participants often perform very well in perceptual tasks, and this is a particular difficulty for learning studies in which floor effects can prevent the observation of much learning. This problem is especially acute in studies of the sensory contributions to LLI. For example, and almost unbelievably, most of the recent literature on developmental dyslexia is based on studies not of stratified samples of children, but of college students who are claiming special consideration in the delivery of their studies on the basis of their dyslexia. At best, these students are likely to have compensated substantially and unusually for their dyslexia. In fact, they typically have normal verbal performance and supra-normal nonverbal performance, the discrepancy leading to their diagnosis. Surely, as a field, we need to make more efforts to recruit and investigate outside of our ivory towers.

The issues we raise in this commentary will, we hope, inspire further research and development in auditory perceptual learning. Despite having a long history, it is a field that only now seems to be finding its feet, either theoretically or experimentally. Most importantly, it is a field that holds enormous promise for the remediation of perceptual difficulties that underlie learning problems. But it will only be through a thorough understanding of the principles of perceptual learning that treatment programs will be designed appropriately and efficiently.

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