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Learning letter identification in peripheral vision

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Abstract

Performance for a variety of visual tasks improves with practice. The purpose of this study was to determine the nature of the processes underlying perceptual learning of identifying letters in peripheral vision. To do so, we tracked changes in contrast thresholds for identifying single letters presented at 10° in the inferior visual field, over a period of six consecutive days. The letters (26 lowercase Times-Roman letters, subtending 1.7°) were embedded within static two-dimensional Gaussian luminance noise, with rms contrast ranging from 0% (no noise) to 20%. We also measured the observers' response consistency using a double-pass method on days 1, 3 and 6, by testing two additional blocks on each of these days at luminance noise of 3% and 20%. These additional blocks were the exact replicates of the corresponding block at the same noise contrast that was tested on the same day. We analyzed our results using both the linear amplifier model (LAM) and the perceptual template model (PTM). Our results showed that following six days of training, the overall reduction (improvement across all noise levels) in contrast threshold for our seven observers averaged 21.6% (range: 17.2–31%). Despite fundamental differences between LAM and PTM, both models show that learning leads to an improvement of the perceptual template (filter) such that the template is more capable of extracting the crucial information from the signal. Results from both the PTM analysis and the double-pass experiment imply that the stimulus-dependent component of the internal noise does not change with learning.

Keywords: Perceptual learning; Training; Letter identification; Peripheral vision

1. Introduction

Performance for a variety of visual tasks improves with practice (e.g. Ball & Sekuler, 1982, 1987; Beard, Levi, & Reich, 1995; Fahle & Edelman, 1993; Fiorentini & Berardi, 1980, 1981; Karni & Sagi, 1991; McKee & Westheimer, 1978; Poggio, Fahle, & Edelman, 1992; Saarinen & Levi, 1995). This improvement is often termed "perceptual learning". Perceptual learning occurs in foveal vision, as well as in peripheral vision (Beard et al., 1995; Chung, 2002; Chung, Legge, & Cheung, 2004). For instance, in the fovea, the ability to judge whether or not two lines are perfectly aligned improves by about 40% after 2000–2500 trials of practice (McKee & Westheimer, 1978). At 5° eccentricity in the periphery, performance for the same task improves by approximately 20% following 6120 trials of practice (Beard et al., 1995).

While strong perceptual learning has been well documented with unfamiliar tasks, e.g. identifying random texture patterns (Gold, Bennett, & Sekuler, 1999) or unfamiliar faces (see Fine & Jacobs, 2002 for a recent review), it is less clear whether learning occurs when the task is highly familiar, such as letter identification.

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Using a letter C stimulus, Westheimer (2001) found that the *acuity* of his observers for identifying the gap of the C stimulus in peripheral vision did not improve with practice. Despite the fact that observers do not habitually use their peripheral vision for identifying letters (which should favor a learning effect), when letter size was used as the metric of performance, there was no improvement with practice. In contrast, when using *percent-correct identification* as the performance measurement, Chung et al. (2004) reported an improvement in performance for identifying the 26 lowercase letters that were approximately twice the acuity-size, following training at 10° eccentricity in the upper or lower visual fields. Thus, improvement in performance is possible even with the highly familiar letter identification task. However, what underlies this improvement? The purpose of this study was to determine the nature of the processes underlying perceptual learning of letter identification in peripheral vision.

Our interest in studying perceptual learning of letter identification in peripheral vision stems from our interest in understanding the limitations and potentialities of peripheral vision in relation to reading. Reading is slow in peripheral vision, and millions of people who lose their central vision as a result of macular diseases such as age-related macular degeneration have to rely on their residual peripheral vision to read. Letter identification is the "bottleneck" for reading (Legge, Mansfield, & Chung, 2001). Pelli, Farell, and Moore (2003) have shown that despite a lifetime of reading, word recognition for even the most common three-letter words is limited by the necessity to "rigorously and independently" detect the features (letters) that comprise the words. Chung et al. (2004) have shown that practice in identifying letters can lead to an improvement in peripheral reading speed. Therefore, an understanding of the nature of the processes underlying perceptual learning in letter identification in peripheral vision might enable the development of strategies to train people with central vision loss to read faster using their residual peripheral vision.

In foveal vision, it has long been suggested that perceptual learning results from a "fine tuning" of the mechanisms underlying the visual task (McKee & Westheimer, 1978). Fiorentini and Berardi (1980, 1981) further suggested that this "fine tuning" of the mechanisms is likely to take place at the early stages of visual processing. Using a simultaneous spatial masking paradigm to unveil the properties of the spatial mechanism underlying Vernier discrimination following training, Saarinen and Levi (1995) found that the improvement in Vernier acuity following training is accompanied by an approximately proportional narrowing of the orientation tuning characteristics of Vernier acuity. However, it was the incorporation of the external noise paradigm into perceptual learning studies in recent years that enabled us to isolate the mechanism underlying perceptual learning. The basis of the external noise paradigm is that the addition of external noise to a signal has a characteristic impact on task performance. To relate the external noise to task performance, very often, we choose to represent task performance by the signal strength required for the observers to reach a threshold criterion of accuracy of performing the task. When plotting the threshold as a function of the external noise on log–log axes, the function shows the characteristic threshold vs. noise curve (TvN), often referred to as the *noise-masking function*. Essentially, when the external noise is low, threshold is relatively independent of the external noise because it is limited by the noise internal to the system. When the external noise exceeds the internal noise of the system, threshold increases in proportion to the external noise (or nearly so). The proportional constant, when compared to that of an ideal observer, reveals how well the system utilizes stimulus information when the internal noise is no longer a limiting factor. The TvN approach thus affords us a way to measure and monitor changes in the internal noise of the system, as well as its ability to extract crucial stimulus information.

In this study, we applied the TvN approach to evaluate learning of letter identification in peripheral vision. In a second experiment we also examined observers' consistency in making their responses when identifying letters embedded in external noise. Burgess and Colborne (1988) first applied a *double-pass method* to analyze observers' consistency in detecting signals in visual noise. The method measures observers' performance through the same sequence of signal-noise combinations (stimuli) twice. Because the stimuli are identical in both passes, any difference in observers' performance can be attributed to observers' consistency, instead of the stimulus. An increase in consistency as a result of learning, particularly in the high external noise condition, would imply a reduction in the internal variability of an observer that was induced by the stimulus (as opposed to internal noise independent of the stimulus). To anticipate, the principal findings from both experiments suggest that improvements in performance due to learning can be attributed to the template (or filter) becoming more capable of extracting the crucial information from the stimuli, but not to a reduction in the observers' internal noise.

2. Methods

To determine the mechanism underlying perceptual learning in identifying letters in peripheral vision, we tracked changes in contrast thresholds for identifying single letters presented in visual noise, at 10° eccentricity in the inferior visual field, over a period of six consecu-