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Learning to identify crowded letters: Does the learning depend on the frequency of training?

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ABSTRACT

Performance for many visual tasks improves with training. The magnitude of improvement following training depends on the training task, number of trials per training session and the total amount of training. Does the magnitude of improvement also depend on the frequency of training sessions? In this study, we compared the learning effect for three groups of normally sighted observers who repeatedly practiced the task of identifying crowded letters in the periphery for six sessions (1000 trials per session), according to three different training schedules—one group received one session of training everyday, the second group received a training session once a week and the third group once every 2 weeks. Following six sessions of training, all observers improved in their performance of identifying crowded letters in the periphery. Most importantly, the magnitudes of improvement were similar across the three training groups. The improvement was accompanied by a reduction in the spatial extent of crowding, an increase in the size of visual span and a reduction in letter-size threshold. The magnitudes of these accompanied improvements were also similar across the three training groups. Our finding that the effectiveness of visual perceptual learning is similar for daily, weekly and biweekly training has significant implication for adopting perceptual learning as an option to improve visual functions for clinical patients.

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). The magnitude of improvement following the process of repeated practice (training), often termed *perceptual learning*, depends on many aspects of the training regime, including the task chosen for training, the total amount of practice and the amount of practice within each training session. Recently, perceptual learning has been proposed as a treatment to improve visual functions or to overcome some of the disabilities as a result of amblyopia (Astle, Webb, & McGraw, 2011; Levi & Li, 2009; Polat, 2009), presbyopia (Polat et al., 2012) and macular disorders (Chung, 2011). A major consideration for applying perceptual learning to improving vision in clinical patients is compliance, which usually relates to the inconveniences brought about by the training regime. For instance, if the training regime calls for many training sessions, or extensive hours of training for each session, patients may find it difficult to adhere to the training schedule. Fortunately, for many visual tasks, improvements usually occur fairly rapidly for the first couple of training sessions (e.g. Fiorentini & Berardi, 1981; Karni & Sagi, 1993; Poggio, Fahle, & Edelman, 1992), although it has been shown that performance for certain tasks could improve slowly after the initial rapid improvement; and may require up to 40–50 h of practice to reach a plateau (Li, Klein, & Levi, 2009; Li, Provost, & Levi, 2007). Also, shorter training sessions have been shown to be more effective in inducing improvements than longer ones (Molloy et al., 2012). Therefore, the number of training sessions and the duration of each session may not be the major factors limiting patient compliance.

Numerous studies that examined perceptual learning in observers with normal vision adopted a protocol in which observers attended daily training sessions (e.g. Chung, 2007; Chung, Legge, & Cheung, 2004; Chung, Levi, & Tjan, 2005), or at the minimum, three to five training sessions per week (e.g. Gold, Bennett, & Sekuler, 1999; Li, Klein, & Levi, 2009; Li, Provost, & Levi, 2007; Saarinen & Levi, 1995; Sun, Chung, & Tjan, 2010). This frequency of training sessions was believed to be crucial to maximize the benefit of perceptual learning. However, is daily training really necessary to obtain the largest amount of improvement? If perceptual learning is to be adopted as a treatment for clinical populations, relaxing the frequency of training sessions is necessary as many patients may not be able to attend daily training sessions. This is especially so for visually impaired patients who are not able

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to drive and thus their availability to attend training sessions would depend on arrangements for transportation. Therefore, the primary goal of this study was to examine the dependence of the efficacy of perceptual learning on the frequency of training sessions. We compared the amount of improvement following perceptual learning in the normal periphery for three training schedules: daily, weekly and biweekly (every 2 weeks). Daily training was the popular schedule used in many previous perceptual learning studies. We chose to evaluate the effectiveness of a weekly and biweekly training schedule because many visually impaired observers are able to participate in research projects in our laboratory once a week or once every 2 weeks, implying that a weekly or biweekly training schedule is feasible for this group of patients. However, it remains unknown whether the effectiveness of perceptual learning would be reduced when there is a longer time interval between training sessions.

Though virtually any training task could be used to address our primary goal, in this study, we trained normally sighted observers to identify letters closely flanked by two other letters (learning to "uncrowd") in the periphery. This training task has been proven to be effective in reducing crowding in the normal periphery (Chung, 2007; Sun, Chung, & Tjan, 2010) and in observers with amblyopia (Chung, Li, & Levi, 2012). Crowding refers to the deleterious influence of nearby contours on visual discrimination (Levi, 2008; Pelli, Palomares, & Majaj, 2004). Previously, we trained observers to identify a letter closely flanked by two other letters, and found that following 6000 trials of repeated testing, observers improved in their ability to identify the flanked letters. This effect was found in the normal periphery (Chung, 2007; Sun, Chung, & Tjan, 2010) as well as in the amblyopic eye of a group of amblyopic observers (Chung et al., 2012). Because our target and flanking letters were randomly chosen from the 26 lowercase letters on each trial, the observed improvements could not be attributed to observers learning a specific combination of letters, as in studies in which only a very limited set of combinations of letters was used for training (e.g. Huckauf & Nazir, 2007). Using a different paradigm in which the letter spacing between the flanking letters and the target letter varied during training, Hussain et al. (2012) reported a similar effect that crowding can be reduced in the normal periphery and in amblyopic observers through perceptual learning. Interestingly, even when the training task was not specifically designed to reduce crowding, such as in video-game playing (e.g. Green & Bavelier, 2007; Li et al., 2011), or using a task that is more closely related to lateral masking than crowding[1] (Maniglia et al., 2011), a reduction in crowding was still observed following perceptual learning. The reduction in crowding was manifested as either better acuities measured in the presence of flankers in close proximity, or a reduction in the target-flanker spacing such that the performance for discriminating some attribute of the target (e.g. contrast or orientation) was not affected (for a review, see Huurneman et al., 2012).

The design of this study closely followed that of Chung (2007) with some modifications. In the Chung (2007) study, despite a substantial improvement in observers' ability to identify crowded letters following a daily training protocol, the improvement did not lead to improved reading speed. Previously, Legge and coworkers showed that the visual span, the number of characters that can be recognized in a single glance, is a sensory bottleneck on reading (Legge, 2007; Legge et al., 2007). This supposition is based on the strong correlation ($r^2 > 0.8$) between reading speed and the size of the visual span (expressed as mutual information transmitted in bits, see Section 2) determined for different stimulus characteristics such as contrast, letter size and stimulus presentation eccentricity.

[1] The distinction between lateral masking and crowding has been addressed in previous studies (Chung, Levi, & Legge, 2001; Pelli et al., 2004).

Given the link between reading speed and visual span, and the finding of Chung (2007), we expected that the visual span, like reading speed, would not benefit from the same uncrowd training task. Such a result would further strengthen the supposition of the visual span as a sensory bottleneck on reading. On the contrary, if the visual span benefits from the uncrowd training task, then the close relationship between the visual span and reading speed would need to be revisited, and the results might help us understand why reducing crowding does not benefit reading speed. The secondary goal of this study was to test if the improvements following a training protocol to learn to uncrowd would lead to an enlargement in the visual span.

To preview our results, we found that observers showed an improved ability to identify crowded letters following six sessions of training. Most importantly, the magnitudes of improvement were similar for the daily, weekly and biweekly training groups. The improvement due to training was accompanied by a reduction in the spatial extent of crowding, an increase in the size of the visual span and a reduction in letter-size threshold. The magnitudes of these (transferred) improvements were also similar among the three training groups.

2. Methods

Twenty-four young adults with normal vision, aged 19–27, participated in this study. Written informed consent was obtained from each observer after the procedures of the experiment were explained and prior to the commencement of data collection. Observers were randomly assigned to one of three training groups, with eight observers in each group.[2] The three training groups differed only on the frequency of the training sessions, with one group receiving training on a daily basis ("daily"), the second group received training on a weekly basis (once a week on the same day of the week, "weekly") and the third group received training every fortnight (once every other week on the same day of the week, "biweekly"). The average ages of the three groups were very similar (daily = 20.13 years, weekly = 20.75 years, biweekly = 20.5 years). All testings (pre-tests, training and post-tests) were performed at 10° eccentricity in the lower visual field.

The basic experimental design and training schedule are represented schematically in Fig. 1. The pre-test, lasted approximately 1.5 h, consisted of the measurements of letter-size threshold, spatial extent of crowding and a visual-span profile (in the order listed). The letter-size threshold was used to determine the letter size that was used in subsequent testings (other pre-tests and training).

Training consisted of six sessions, each lasting approximately 1 h. The training task was very similar to that used in Chung (2007), whereby observers identified a letter flanked closely by two other letters on each trial, at 10° in the inferior visual field (Fig. 2A). The only differences between this study and Chung (2007) were that we used Courier font in this study (Times font was used in Chung (2007)) and that we specified the letter separation with respect to the standard letter spacing (equivalent to

[2] A power analysis for ANOVA designs revealed that our sample size of eight observers per group yielded a power of 0.999 to detect any effect at $p = 0.05$, for our training task of identifying crowded letters, as well as for the untrained tasks of spatial extent of crowding measurements and visual-span measurements. For the trained task of identifying crowded letters, we assumed an improvement in proportion-correct of 0.181, with a standard deviation of 0.048 (values based on finding of Chung (2007)). This yielded an effect size of 3.77. For the untrained tasks, the assumed effect sizes were 6.783 (average post-pre ratio = 0.624, standard deviation = 0.092, based on Chung (2007)) for the spatial extent of crowding measurements; and 3.414 (average improvements in bits = 6.1, standard deviation = 1.787, based on Chung, Legge, and Cheung (2004)) for visual-span measurements.