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*Original Article*

# Perceptual learning: a novel method to improve the near reading abilities in early stage presbyopia patients

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**Abstract:** Objective: This study aims to investigate the effects of perceptual learning in subjects with early stage presbyopia. Methods: Forty subjects (40 eyes) with presbyopia were recruited and divided into two groups, randomly. Treatment group received practice with perceptual learning software. Another group was allocated to the blank control group. Reading acuity, maximum reading speed, critical print size, and central lens thickness changes in amplitude of accommodation were measured using the reading visual acuity chart and the AS-OCT (Anterior Segment Optical Coherence Tomographer) for each subject at five time points: before treatment and at 3, 6, 9 and 12 weeks during the perceptual learning treatment. Functional magnetic resonance imaging (fMRI) data were acquired for treatment group twice: before and after 12 weeks of perceptual learning treatment. Results: After 12 weeks treatment, the treatment group achieved a mean improvement from 5.15±1.10 pt (point) to 3.95±0.75 pt in reading acuity (F = 22.92, P<0.05); a mean improvement from 317.07±33.29 w/m (words per minute) to 324.70±31.89 w/m in maximum reading speed (F = 4.83, P<0.05); a mean improvement from 18.43±3.22 pt to 14.73±2.76 pt in critical print size (F = 29.39, P<0.05). Central lens thickness changes in amplitude of accommodation were little changes in treatment group, from 0.0429±0.0124 mm to 0.0428±0.0125 mm (F = 0.79, P = 0.38). The control group did not show any significant change in reading acuity, maximum reading speed, critical print size, and central lens thickness changes in amplitude of accommodation. Comparisons of treatment and control groups revealed statistical differences in reading acuity, maximum reading speed, and critical print size (F = 30.34, F = 4.55, F = 41.49, all P<0.05), which interacted between two factors (time × groups), but central lens thickness changes in amplitude of accommodation was not found statistically differences (F = 1.06, P = 0.31). Increased activation via presbyopic eyes was found in BA (Brodmann Area) 17-19, left fusiform gyrus, lingual gyrus and right occipital gyrus, cuneus, after the perceptual learning treatment. Conclusion: Our findings suggest that perceptual learning can improve the near reading abilities in patients with early stage presbyopia and the improvements are not due to the changes of lens, rather, it is likely to rely on the plasticity of BA 17-19.

**Keywords:** Perceptual learning, presbyopia, near reading abilities

## Introduction

Presbyopia is an age-related near-vision impairment thought to arise primarily by the loss of accommodation. Lu *et al* found in 776 Chinese >40 years using population-based cross-sectional surveying that the 538 (69%) persons with presbyopia [1]. With the widespread use of computers and smartphones, the longer daily duration of vision at the monitor have a strong negative effect among the people in the early stages of presbyopia [2]. Perceptual learning refers to the phenomenon that practice or training in perpetual tasks often substantially improves perpetual performance [3]. Recently, researchers found that perceptual learning could improve unaided contrast sensitivity function, suprathreshold contrast discrimination and reading speed for small letters in patients with low myopia, or adult hypermetropic anisometropic amblyopia [4, 5].

In present study, we evaluated the impact of perceptual learning on the near reading abilities (reading acuity, maximum read speed and critical print size), central lens thickness changes in amplitude of accommodation, and activation of visual cortex in early stage presbyopia patients using the Chinese reading visual acuity chart, the AS-OCT and fMRI techniques, respectively.

## Materials and methods

### *Subjects*

Twenty males and twenty females (age range 40-45 years, mean age 42.3±2.5 years old) with early stage presbyopia were randomly selected from patients referred to the Department of Ophthalmology of Shanghai Tongji Hospital. Written informed consents were obtained before the examination. Recruitment according to the definition of presbyopia (functional presbyopia) was binocular near vision <N8 (20/50) at 40 cm with habitually worn distance refractive correction, with improvement of near vision by at least one line on near logMAR E chart with the use of a plus lens and need for stronger lighting to read [6, 7]. Subjects were divided averagely and randomly into two groups: perceptual learning treatment group and control group. The control group underwent the same examination at the same intervals as the treatment group but just did not receive the perceptual learning treatment. All subjects were right-handed and they had no neurological dysfunction or known organic eye diseases that could affect vision quality, such as cataracts, macular degeneration, dry eyes, and conjunctivitis.

### *Perceptual learning treatment*

The perceptual learning therapy program (GlassesOff, version.1.0.038, USA) is based on visual stimulation by Gabor patches [8, 9]. As a noninvasive, patient-specific, interactive panel computer (IPAD, Model A1219, U.S. Apple Corp) software, its training session lasted for approximately 12-15 minutes per time and was conducted 3 times per week for a period of 3 months. During the session, subject sat 1ft (about 30 cm) away from the panel computer screen in a quiet and darkened room (150~200 lx). They were instructed to respond to visual perceptual tasks displayed on the screen where the brightness was automatically adjusted. Only the eye with the minimum amplitude of accommodation was trained for each subject. The amplitude of accommodation was measured by the push-up to blur technique and a small letter target [10]. After each training session, subject's performance in visual perception tasks was recorded and sent to the server.

### *Reading acuity, maximum read speed and critical print size acquisition*

*The Chinese Reading Visual Acuity Chart* designed by Wang *et al* was used to evaluate the near reading abilities, including reading acuity, maximum read speed and critical print size [11]. The chart contains 39 sentences with print size range from 1.3 logMAR to 0.1 logMAR at a distance of 40 cm. Each sentence consisted of 27 commonly-used characters (9 characters between any two punctuations) and 3 punctuations. Characters had 13 different sizes; an increment of 0.1 log unit and 2.5 pt (point) was determined as critical threshold. Different charts were used for pre and post-treatment; all tests were conducted in a quiet and well-lit room (≥300 lx). The chart was placed on 40 cm away from subject, who was asked to read each sentence aloud as quickly and as accurately as possible. Stopwatch software (Recorder plus, Version 2.0.3, Turbokey Studio) was used to record the time taken to read each sentence to the nearest 0.01s. The number of errors made in each sentence was also recorded. Reading acuity was calculated as the logMAR of the last sentence read, adding 0.0037 logMAR for each character reading error. Reading speed was measured in words per minute. Maximum reading speed was calculated as the fastest sentence read, regardless of logMAR. Critical print size was measured as the smallest print size that the participants could read close to their maximum reading speed. The results of reading acuity and critical print size were converted to points.

### *Central lens thickness changes in amplitude of accommodation by AS-OCT*

The cross-sectional images of crystalline lens were taken by the AS-OCT (Carl Zeiss Meditec, Germany) [12]. Subject's refractive error was determined from an average of three measurements using the auto ref/keratometer (NIDEK, ARK-510A, Japan) and compensated within the AS-OCT unit by the internal optometer. Subject was instructed to fixate the internal target, keeping it as sharp, clear, and in-focus as possible. "Raw Image" mode was used to obtained

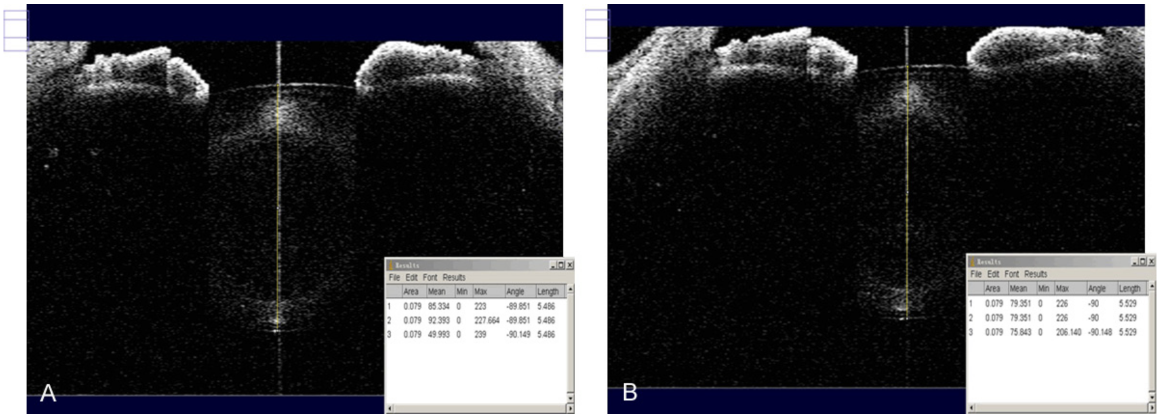


**Figure 1.** Image of lens obtained with AS-OCT and the measuring process with Image J. The white line through the image is the fixation line and was used to ensure measurement through the center of lens. A. Image of len thickness when subject's refractive error was compensated; B. Maximum accommodation was stimulated by using the internal optometer at diopter measured previously.

images of crystalline lens, and subsequently exported and analyzed using Image J software (National Institutes of Health, United States Department of Health and Human Services) by one examiner. This analysis was repeated three times and resulting lens thickness were averaged (**Figure 1**). Maximum accommodative response was stimulated by adjusting the internal optometer, in 0.5 D steps.

*fMRI data processing*

A block design fMRI paradigm was used in this study. All subjects received text stimulus, which was based on the E-Prime v1.1 (Psychology Software Tools, Inc., USA) software [13]. Stimulus was back-projected onto a translucent screen on the scanner bed and controlled by a workstation (Smartec SA-8800 fMRI Stimulation system, Shenzhen Sinorad Medical Electronics Inc., China). An angled mirror positioned above subject's eyes, provided subject with a full view of the screen. Silk eye patch covered the non-testing eye.

Imaging was performed on a Siemens Sonata 3.0 Tesla MR scanner [14]. Subject was in a supine position, with his/her head immobilized using a vacuum pillow; earplugs were used to reduce scanner noise, and a helmet was positioned onto the same platform. Conventional axial T1-weighted images were obtained with a spin-echo (SE) imaging sequence with the following acquisition parameters: repetition time (TR) = 2530 ms, echo time (TE) = 2.34 ms, field of view (FOV) = 256 × 256, matrix = 256 × 256, slice thickness/gap = 1.0/0.5 mm, flip angle = 7°; BOLD images data were acquired with a gradient echo-echo planner imaging (GRE-EPI) sequence. The scanning parameters for BOLD imaging were: repetition time (TR) = 2000 ms, echo time (TE) = 30 ms, field of view (FOV) = 192 × 192, matrix = 64 × 64, slice thickness/gap = 4.5/0 mm, flip angle = 90°. Two separate MRI scans were performed on the treatment group: one before the treatment and then following the treatment. Considering that is easy to envision a non-training control group is unlikely to show improvement in real life, a non-training control group was not included. Each scan contained four resting-state blocks, interleaved by four stimulation-state blocks.

The MRI images were analysed with Matlab V.7.8 (The Math Works, Inc., Natick, Massachusetts, USA) using the statistical parametric mapping software SPM8 (http://www.fil.ion.ucl.ac.uk /spm/software/spm8). Transient effects of the haemodynamic responses were minimised by excluding the images from the first 10 s of each block. Images with a head motion more than 2.0 mm in translation or 2.0° in rotation were also excluded. The imaging data were fitted to the standard Talairach template in order to compensate for variations in the global signal and individual differences.

*Statistical analysis*

Repeated measures analysis of variance (ANOVA) was performed on the measurements of reading acuity, maximum read speed, critical

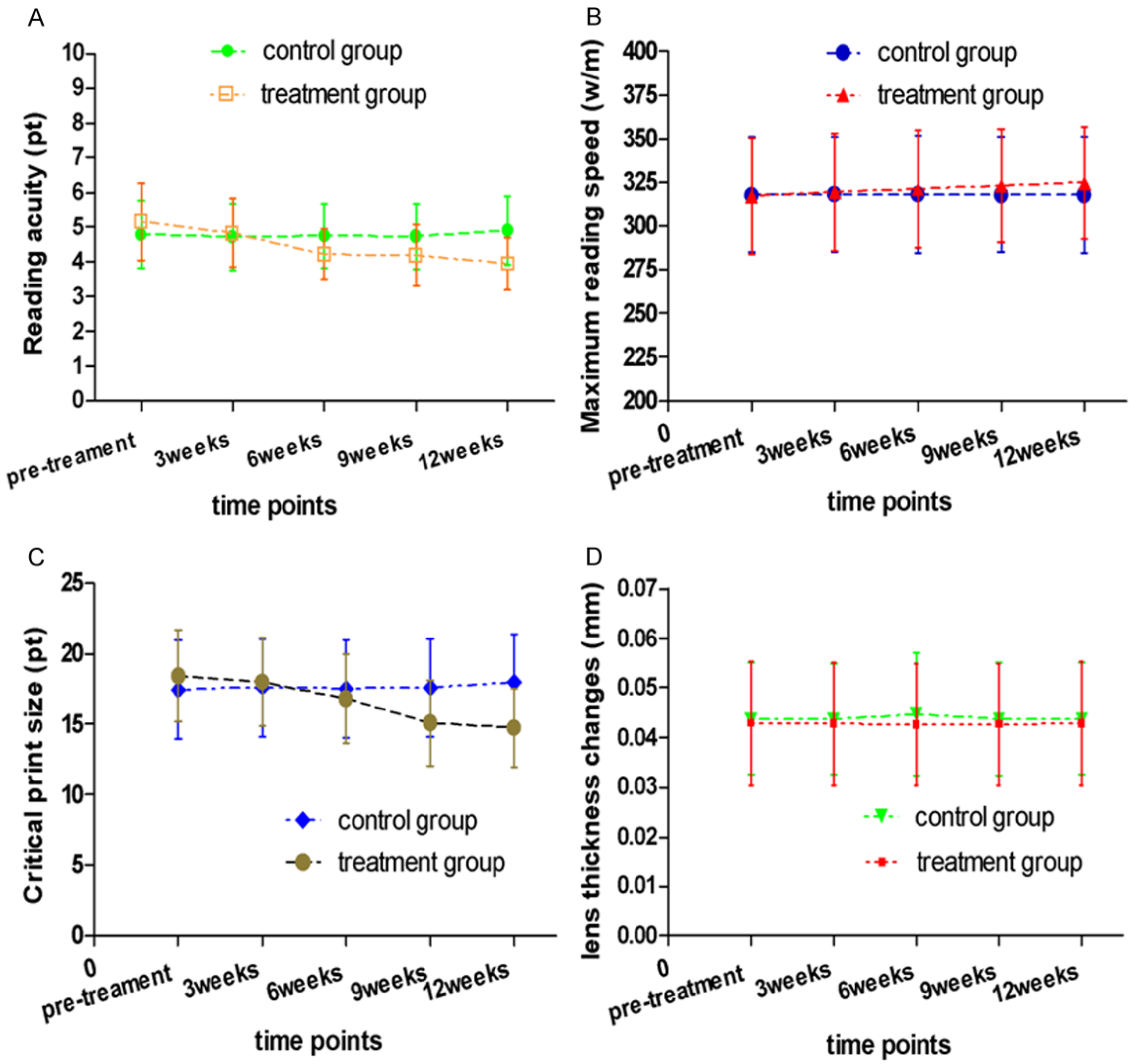


**Figure 2.** Mean difference of reading acuity (A), maximum reading speed (B), critical print size (C), and central lens thickness changes in amplitude of accommodation (D) between control and treatment groups at different times. Error bars represent SE of the mean.

print size and central lens thickness changes in amplitude of accommodation after a test of normality and a test of variance homogeneity. Statistical calculations were performed using SPSS 14.0 (Statistical Product and Service Solutions 14.0, IBM Company, USA). The results were Greenhouse-Geisser corrected. P<0.05 was considered statistically significant.

Activation maps were calculated by comparing images acquired during the stimulation and resting states, using an unpaired *t*-test. Paired *t*-tests were used to compare the cortical activity induced by visual stimulation through the treatment group before and after treatment. For the data analysis, we used a significance level of P<0.001, extent threshold = 10 voxels. Talairach Client (http://www.talairach.org/client.html) software was used to identify the Brodmann Area (BA) and anatomical position of the cortical activation.

## Results

*Reading abilities and lens thickness changes in amplitude of accommodation*

Comparison of the reading acuity, maximum reading speed and critical print size between the control group and the treatment group revealed a statistically difference with time in both groups (F = 22.92, F = 4.83, F = 29.39, all

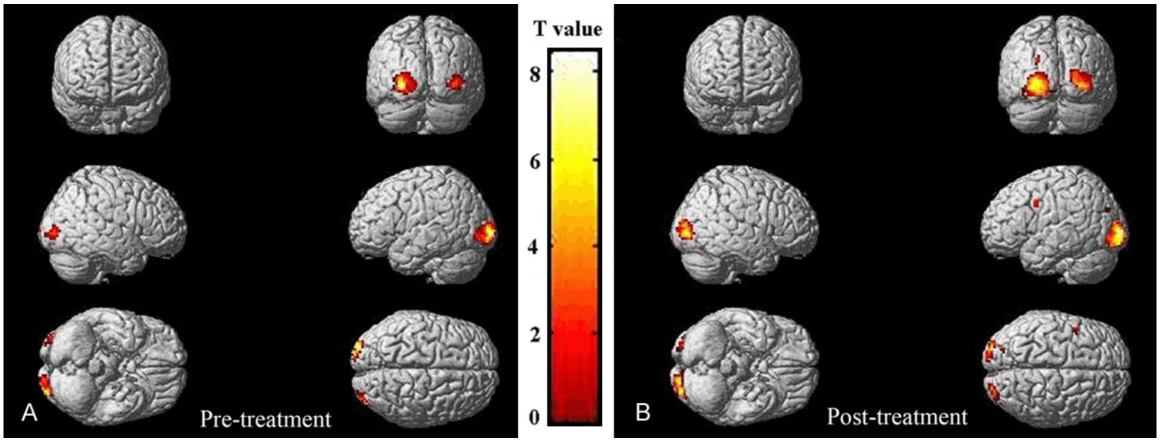


**Figure 3.** Images indicated the areas significantly activated by stimuli from different perspectives. These were defined by comparing the response to gratings versus gray. The color bar denotes the T value. The brain areas exhibited significant differences by the same stimuli in subjects who perceived the perceptual learning treatment.

**Table 1.** The areas showing increased cortical activation with stimulation delivered through the presbyopic eyes after perceptual learning (n = 20)

| Activation area | BA | Talairach coordinate | | | T value | Voxel number |
|---|---|---|---|---|---|---|
| | | X | Y | Z | | |
| Left fusiform gyrus | 18 | -27 | -90 | -12 | 3.54 | 67 |
| Left lingual gyrus | 18 | -24 | -99 | -3 | 5.09 | 94 |
| Right superior occipital gyrus | 19 | 33 | -78 | 27 | 3.08 | 56 |
| Right cuneus | 17 | 21 | -93 | -3 | 5.43 | 63 |
| Right inferior occipital gyrus | 18 | 33 | -84 | -6 | 5.33 | 87 |

BA: Brodmann area; *P*<0.001, extent threshold = 10 voxels.

P<0.05), but no significant difference between groups (F = 2.79, F = 0.18, F = 2.1, all P>0.05). Interaction between two factors (time × groups) was statistically significant (F = 30.34, F = 4.55, F = 41.49, all P<0.05), central lens thickness changes in amplitude of accommodation was not found statistically differences (F = 0.79, F = 0.46, F = 1.06, all P>0.05) (**Figure 2**).

*Changes of cortical activity*

The main active areas were the BA 17, 18 and 19 for the treatment group, with significant increases in cortical activation after 3 months of perceptual learning treatment (P<0.001, extent threshold = 10 voxels) (**Figure 3**; **Table 1**).

## Discussion

The underlying cause of presbyopia remains undefined and the mechanism of accommodation is still debated [15, 16]. Classical theory proposed by Helmholtz suggested that accommodation may be induced by a contraction of the ciliary muscle [17]. This theory was challenged by Schachar, he thought that presbyopia occurs as the equatorial diameter increased of the aging lens increases [18].

Methods for the correction of presbyopia included contact lens, spectacle options and surgical strategies for correcting presbyopia may be corneal ablation, intrastromal femtosecond ring incisions, corneal inlays, different lens removal and replacement with an intraocular and scleral modification [19]. As a non-invasive method, perceptual learning will be more popular than surgical procedures. In our study, subjects from the treatment group were able to read smaller characters on an acuity chart or text of smaller size and read faster than before treatment, it is very important in daily life. And these improvements were reported could be retained for at least 12 months in similar study [20]. The presented data provide a proof that the training program of perceptual learning is an effective approach for individuals with early stage presbyopia.

However, we also found that central lens thickness changes in amplitude of accommodation of these patients did not show any significant differences, which implies that the improvement of the near reading abilities in the treatment group was not a result of the changes of lens. And Polat *et al* also show that perpetual learning improves suprathreshold contrast discrimination and reading speed for small letters, but these improvements were not due to improved optical performance of the eye (accommodation, pupil size or depth of focus) [8]. It means that these improvements can't beyond the physiological limitation of age. Moreover, here we first to show that the cortical activation increased during presbyopic eye stimulation after 3 months of perceptual learning treatment were in BA 17, 18 and 19 using fMRI techniques. BA 17 is also called the striate cortex, which is the primary visual cortex; BA 18 and BA 19 belong to the extrastriate cortex, their role is further processing of visual information from the primary processing in BA 17, so their structures and functions are more complex. As evidence that the limited plasticity is still retained in visual cortex for improving the near reading abilities with early stage presbyopia. This conclusion is also consistent with the inferences of Chang *et al*, and they thought that the degree of change may be associated with individual visual plasticity [21].

Our results indicate that perceptual learning treatment for early stage presbyopia has a positive effect on the near reading abilities and visual cortex. However, the study still has some limitations, such as the small sample size and the lack of follow-up information regarding whether the vision improvements were maintained.

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