Effects of Visual Rehabilitation on a Child With Severe Visual Impairment

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- evoked potentials, visual
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We examined the effects of visual rehabilitation, including a chromatic luminance discrimination program and a fixation training program, on a 6-yr-old boy with severe visual impairment. Single-subject ABA and AB designs were used. The programs were conducted 2x/wk and included 6 to 7 sessions for the baseline phase and 10 to 11 sessions for the intervention phase. Play was integrated into the visual training programs. Goggle visual evoked potential (VEP) testing was used to evaluate neural activity in the primary visual cortex. Correct responses increased and response times were shortened after training in luminance discrimination. The total and maximum fixation time also improved, as did P100 latency and amplitude of VEPs. While walking, the boy was able to detect obstacles he had not noticed before training. The results indicate the value of visual training and the possibility of brain plasticity in a child with severe visual impairment.


Visual functions, which include visual acuity, contrast sensitivity, color perception, oculomotor control, and so forth, serve an important role during a child’s development (Lueck, 2004). In children, impaired vision can contribute to a wide range of problems in motor areas, language, psychosocial function, and activities of daily living (ADLs; Brambring, 2006, 2007; McAlpine & Moore, 1995; Pring, Dewart, & Brockbank, 1998; Snow-Russel, 2001). Although high variability exists in these problems, the level of visual impairment is associated with the severity of these developmental problems (Brambring, 2006, 2007; McAlpine & Moore, 1995; Pring et al., 1998). We define visual impairment as best corrected central visual acuity of 20/60 in the better eye or visual fields no greater than 20°.

Several intervention strategies have been suggested to reduce the limitations caused by visual impairment (Snow-Russel, 2001). Compared with compensatory strategies, such as developing optimal tactile- and auditory-perceptual abilities, maximizing residual visual functions in clinical practice has received less attention. In fact, even children with severe visual impairment—defined as visual acuity less than 20/2000—still have some residual visual functions, such as light orientation, motion perception, and luminance discrimination. In general, maximizing these sparse residual visual functions may increase the motivation of these children to explore their environments, improve their performance in ADLs, and thus improve their quality of life, especially in children who have only visual problems (Lueck, 2004). Moreover, the gain in visual skills in children with severe visual impairment is not stagnant but can improve continuously to some extent through spontaneous development (Good, Jan, Burden, Skoczenski, & Candy, 2001; Lim et al., 2005) and visual training (Baker-Nobles & Rutherford, 1995; Leguire, 1992; Malkowicz, Myers, & Leisman, 2006; Sonksen, Petrie, & Drew, 1991; Werth & Seelos, 2005).
Thus, increasing residual vision should be addressed along with other compensatory strategies for children with severe visual impairment (Good et al., 2001).

Visual impairment is usually classified as involving anterior and posterior visual pathway lesions according to the anatomical location of the lesions. Visual lesions before the lateral geniculate body, including the eyeball and optic nerve, are called anterior visual impairment. Damage to the optic radiations and visual cortex is called posterior visual impairment (Baker-Nobles & Rutherford, 1995; Good et al., 1994). Although both types of lesions can impair visual function and even cause blindness, they differ in several ways. For example, people with anterior (or ocular) visual impairment usually have no or sluggish light reflex coupled with involuntary roving eye movement (Baker-Nobles & Rutherford, 1995; Levin & Arnold, 2005). Posterior (or cortical) visual impairment is usually combined with cognitive or other neurological deficits, such as hypertonia, hemiparesis, microcephaly, or seizures (Good et al., 1994).

Several validation studies have supported the efficacy of a remedial approach in visual rehabilitation for children with visual impairment. Intensive visual stimulation and visual field training have produced significant visual progress in intervention groups (Baker-Nobles & Rutherford, 1995; Leguire, 1992; Malkowicz et al., 2006; Sonksen et al., 1991; Werth & Seelos, 2005). The participants in these studies had cortical visual impairment (Baker-Nobles & Rutherford, 1995; Malkowicz et al., 2006; Werth & Seelos, 2005) or both types of lesions (Lagueure, 1992; Sonksen et al., 1991). Regardless of which visual pathway was defective, these children's visual functions and functional vision could be restored after systematic visual training.

Most children included in these intervention studies were in their visual sensitive period. As in normal-sighted children, critical periods in visual development exist in children with visual impairment (Lewis & Maurer, 2005). Visual functions with different developmental time courses develop quickly during the visual critical periods and gradually reach a plateau after the sensitive periods (Lewis & Maurer, 2005). Therefore, the necessity of a remedial approach to visual rehabilitation for older children with visual impairment, and especially severe visual impairment, has been questioned for a long time. Recent studies of children with amblyopia, however, have suggested that experience-dependent plasticity for change exists even beyond the traditional visual critical periods after visual–perceptual learning (Hussain, Webb, Astle, & McGraw, 2012; Scheiman et al., 2005). Nevertheless, little evidence exists to validate the efficacy of a remedial approach for older children with severe visual problems. Therefore, whether to allocate visual rehabilitation resources to older children with severe visual impairment is still a controversial issue.

Experience-dependent plasticity means that the brain learns or relearns new behaviors in response to internal or external stimulation (Draganski & May, 2008). Learning is an essential element to alter the brain’s structure and function. Visual–perceptual learning involves improving one’s ability, through extensive exposure and training, to discriminate differences in the attributes of complex or simple visual stimuli (Gilbert, Sigman, & Crist, 2001). Several studies have indicated that visual–perceptual training could change the neural activities in the primary visual cortex (Sagi, 2011). The process of visual–perceptual learning follows the principles of bottom-up and top-down modulation (Gilbert et al., 2001). Cognition, such as knowledge and expectation, and attention are important controlling factors during the top-down process (Sasaki, Nanez, & Watanabe, 2010). Nevertheless, typical perceptual learning programs usually demand repetitive and monotonous practice for a period of time, thus making them less suitable for children. Therefore, modified perceptual learning programs usually demand repetitive and monotonous practice for a period of time, thus making them less suitable for children. Therefore, modified perceptual learning programs, such as combining video gaming with contrast training, are suggested for children (Nazemi, Markowitz, & Kraft, 2008; Polat, Ma-Naim, & Spierer, 2009). Modified perceptual learning programs could attract more active participation and attention to facilitate the perceptual learning effect. It remains undetermined, however, whether modified perceptual learning could be applied to children with severe visual impairment to ameliorate their basic visual functions.

In this study, we examined whether intensive visual training could improve visual functions in an older child with severe visual impairment. We hypothesized, on the basis of the principles of experience-dependent plasticity, that residual visual functions in older children with severe visual impairment could still be enhanced. After initial evaluation, we set two training goals for our participant—improving the capacity of chromatic luminance discrimination and increasing the ability of visual fixation. The results showed the value of intensive visual training and the plastic potential in an older child with severe visual impairment.

**Method**

**Case Description**

The subject was a 6-yr-old boy. His gestational age was 36 wk, and he had a history of short-term asphyxia at birth. Poor light awareness and poor visual searching behaviors
were found at age 6 mo. Normal fundoscopy and a normal brain MRI study were reported at that time. He was recruited from the Taipei Parents’ Association for the Visually Impaired. The boy’s parents gave written informed consent for this study.

Neuro-ophthalmological examinations, electroretinogram (ERG), and goggle visual evoked potential (VEP) testing were arranged before training. The ERG, which is composed of electrical potentials contributed by the retina to light stimuli, can be used to evaluate retina function. Goggle VEP testing is used to measure the integration of the entire visual pathway, including the eyes, optic nerves, optic radiations, and primary visual cortex. It is useful in patients whose visual functions are severely impaired or who are unable or unwilling to cooperate. Ocular examinations of the child showed clear media, normally looking retinas, and normal optic nerves. Fundus photo examination demonstrated an oval-shaped and pigmented macula and a pinkish, regular-margin optic disc with no sign of papilledema. He had slight pupil reflex to light and was poor at recognizing a penlight in a dark room. Light perception was more sensitive in the left eye than in the right eye. Limited visual fixation and roving eye movement, which indicated visual cortex dysfunction with sparing of extraocular muscle control, were also noted. He had very weak and slow hand-movement vision in both eyes. The optokinetic nystagmus was absent. Although ERG was arranged for the child, he could not finish the test because of poor cooperation. VEP testing revealed significant delayed response (Figure 1A).

No apparent neurological deficits were noted. Although short-term asphyxia was recorded at birth, normal brain MRI excluded hypoxic encephalopathy or other structural lesions, which are known to cause posterior visual impairment, and small lesions in the visual cortex do not cause a severe visual deficit (Good et al., 1994). Therefore, Leber congenital amaurosis (anterior pathway lesion) with severe visual impairment was suspected for this child on the basis of normal MRI and normal fundus study with poor visual reflex; no ERG result was available.

The subject attended regular kindergarten and received special education once a week. The goals of special education were to enhance his tactile–perceptual abilities, pre-Braille skills, and basic orientation and mobility skills. Orientation and mobility instruction refers to teaching students with visual impairment to move safely and effectively through their environment as independently as possible. He was able to participate in all kinds of activities in school, except for those requiring highly coordinated motor skills. Although he could move around the classroom, he usually stayed in his seat during the rest time to listen to what other children were doing.

Rationales for Designing Visual Training Programs

We had three main rationales for developing our visual training programs, including the application of visual neuroscience, the framework of visual development, and consideration of specific visual characteristics in children with severe visual impairment.

Visual Neuroscience. Visual signal transmission is a complex process that combines the functions of the anterior and posterior visual pathways, oculomotor control, and higher cortical functions. Visual information is collected through simple elements, such as orientation, contrast, and color, at the early stages of vision (Grill-Spector & Malach, 2004); early stages refers to the passage from the retina to the primary visual cortex. These simple elements are then integrated in the later stages of the visual cortex. In addition to feed-forward hierarchical processing, top-down modulation, such as attention control, can enhance neural activations in the early stages of vision (Grill-Spector & Malach, 2004). The properties of visual information processing provided the basic framework to construct our remedial visual training

![Figure 1. Results of goggle visual evoked potential testing. (A) Pretraining, delayed P100 response, P100 = 142 ms; (B) post-training, shortening latency and better waveform of P100, P100 = 110 ms.]
programs, including the types of visual stimulus and content of training activities. In addition, evidence of brain plasticity supports the connection between visual neuroscience and clinical application (Guzzetta et al., 2010).

Visual Development. Although children with severe visual impairment have limited visual capacity, their vision follows the principles of normal visual development (Erhardt, 1990). Light perception, light orientation, and light sensitivity develop first. Contrast perception, color perception, visual acuity, and visually guided motor responses develop later (Lueck, 2004). Among these visual functions, visual acuity is the primary focus in describing the degree of visual impairment. However, for children with severe impairment, contrast sensitivity is considered to be a better predictor of functional vision than visual acuity (Lueck, 2004). Because visual acuity is defined as the ability to resolve small and high-contrast targets, it does not provide the best assessment of visual performance in real-world environments. Children with the same visual acuity can function quite differently depending on their ability to perceive and discriminate contrast (Lueck, 2004). Also, several visual and visual–motor functions, such as visual attentiveness, color perception, and object recognition during locomotion, are dependent on the perception of stimulus contrast (Shapley, 1986).

Contrast is determined by the difference in luminance between objects and background. Contrast sensitivity is the ability to discriminate objects that vary slightly in relative luminance (DeValois & DeValois, 1988). Luminance is the physical property of emitting or reflecting light. Contrast is a broad topic area that is often manipulated in visual rehabilitation fields in two ways: achromatic and chromatic luminance (Lundervold, Lewin, & Irvin, 1987). Although contrast perception is important for children with severe visual impairment, less attention is paid to contrast perception than to visual acuity (Lueck, 2004).

Characteristics of Severe Visual Impairment. An important visual characteristic of children with severe visual impairment is the pattern of oculomotor control. Visual input is a prerequisite to stimulating the development of all classes of eye movement. Lack of the “seeing” experience causes roving eye movement and short fixation time, which are usually present in children with severe visual impairment (Erhardt, 1990). Abnormal eye movement in turn may deteriorate the maturation of the visual cortex because of the lack of visual stimulation. Moreover, shortened fixation in these children also limits their ability to gather completely their “visible” visual information around them.

Goals of Visual Rehabilitation

On the basis of the previously described rationale and the results of visual function assessment, we set two training goals for the current study after discussions among the research team and consultations with the child’s parents. The first goal was to increase the child’s ability to discriminate chromatic luminance. The second was to improve the duration time of visual fixation.

We selected a perceptual learning task for discriminating chromatic contrast luminance to stimulate the early vision development of our participant. Because contrast sensitivity is a good predictor of functional vision (Lueck, 2004), we supposed that improved contrast sensitivity might bring about some improvement in this child’s occupational performance. In addition, because of our belief that the ability of visual fixation is the basis of residual visual function, we included fixation training as another research goal.

We modified the perceptual learning program to focus on merging the visual training into play activities. Because play is a functional task for children, it can facilitate and modulate children’s motivation and attention during training, further enhancing the visual learning effect. Thus, we expected the modified visual–perceptual learning to address not only the impairment, but also functional performance through repetitive task practice (Hubbard, Parsons, Neilson, & Carey, 2009). For play activities, we manipulated the luminance, color, and contrast components of training materials and the environment so that the child would use his eyes during play. We expected that because of these manipulations, he would be more likely to translate his new learning abilities to his daily activities.

Research Design

This study consisted of two training programs; each training session with the child included both programs. A single-subject ABA design was used for the chromatic luminance discrimination program consisting of a no-treatment baseline phase (A1), followed by a treatment phase of chromatic luminance discrimination training (B) and a follow-up phase (A2). For the visual fixation program, a single-subject AB design was used. The child did not receive any specific training for improving fixation during the baseline phase (A); the visual fixation training was then introduced during the treatment phase (B).

This training was conducted by an occupational therapist, the first author of this study (Tsai), working at the Taipei Parents’ Association for the Visually Impaired who had more than 6 yr experience in the pediatric visual...
training field. Training sessions were held 2×/wk; the chromatic luminance discrimination program consisted of 20 sessions (6 baseline, 10 treatment, 4 follow-up), and the visual fixation program consisted of 17 sessions (7 baseline, 10 treatment). Each session took about 40–50 min, including treatment and assessment. Most data were collected before the training began. The sequence of introducing the chromatic luminance discrimination program and the visual fixation program in a session was randomized. The child had breaks of 10–15 min between the two types of training.

Program for Increasing Chromatic Luminance Discrimination

Major equipment used included a 14-in. IBM ThinkPad T42 (IBM, Armonk, NY) with Microsoft Office PowerPoint XP (Microsoft, Redmond, WA) and a variety of 26 cm × 36 cm plastic cards with the colors red, green, yellow, white, and black. The light level of the treatment environment was constant throughout this study.

Stage 1 of treatment, Sessions 1–5, consisted of repeated perceptual learning of color recognition and color discrimination in a room with dim light. Solid-colored circles with a radius of 6 cm on a black background were generated with Microsoft Office PowerPoint XP and presented in the center of the screen at a viewing distance of 50 cm to 60 cm. The circles were red (red, green, blue [RGB] color model: 255, 0, 0), green (RGB: 0, 255, 0), and yellow (RGB: 255, 255, 0). There were three training blocks, and every block had 21 training trials in each session. In the first block, the sequence of presenting red, green, and yellow circles was fixed. In the second block, the sequence was randomized. Each circle was displayed for 6 s, and the interstimulus was a black field filling the whole screen. The interstimulus interval was 3 s.

The child was encouraged to name the color he perceived from the screen. If the answer was not correct, the trainer would provide the correct answer and encourage him to recognize the color again and commit to memory what he was sensing at the moment. In the third block, the circle (target color) was displayed for 8 s, and then two colored squares, one of them the target color, were presented simultaneously on the screen. The child’s task was to judge which side (left or right) contained the target color. The trainer provided feedback on incorrect responses.

In Stage 2 of treatment, Sessions 6–9, the intervention was carried out under normal indoor light. The third block in Stage 1 was followed by Stage 2. In addition, the activity of matching the color of the circle on the screen with the same color among five plastic cards was added in Stage 2. All activities were incorporated into a role-play, such as selling different kinds of fruit, to increase the child’s active participation.

Program for Improving Visual Fixation

In Stage 1 of the visual fixation program, light sources such as a flashlight, penlight, or tensor lamp were used. The child could detect these kinds of light sources easily in a dimly lit environment, so these materials were incorporated with interesting toys or play activities to increase his motivation to fixate on them. For example, the child role-played a truck driver transporting fruit from the country to the city, following the direction of the flashlight. At first, the flashlight was combined with slight motion to increase his awareness of light positions.

In Stage 2, Sessions 4–10, intervention was conducted under normal indoor light conditions. Light-reflecting objects and large colorful objects were incorporated with play to increase the duration of visual fixation.

Outcome Measures

To validate the strength of visual rehabilitation, both electrophysiological and behavioral measures were obtained. All behavioral measurements were performed by the same examiner (the first author) during the study. Behavioral data were collected before the training program in most sessions to prevent fatigue that could compromise the results. Goggle VEP testing was conducted before and after the training course.

For the chromatic luminance discrimination program, visual stimuli, the child’s response rate, and his response time were generated and recorded by SuperLab 2.0 software (Cedrus Corporation, San Pedro, CA) on the IBM ThinkPad. The red, green, and yellow colors filled the whole screen. The viewing distance was 50 cm. No time limit was imposed, and the visual stimuli were presented until the child gave a response. His task was to choose the color he perceived under dim light conditions. There were 3 blocks of 18 trials, with red, green, and yellow appearing equally. Therefore, the total score for each color of luminance discrimination was 18 points. The sequences of presenting red, green, and yellow in each block were pseudorandom. The chromatic luminance of the red was darker than that of the yellow and green. The luminance of the yellow was close to that of the green.

In the visual fixation program, the fixation behaviors were recorded by a webcam. The child’s task was to look steadily at a colorful puppet at a distance of 30 cm under normal indoor lighting. The puppet was swayed slightly
and intermittently to attract the subject’s visual awareness and visual attention. The size of the puppet was 17 cm × 12 cm. After the fixation assessment, the examiner and the child’s mother reviewed the video together and decided which sections of the video displayed fixation behaviors. The maximum and total lengths of fixation time during a 2-min span were recorded.

In addition to visual behavioral assessment, goggle VEP testing was used to evaluate the training effect. The goggle VEP testing indicated the integration of the visual pathway, including the eyes, retina, optic nerves, optic radiations, and primary visual cortex. Because chromatic luminance is involved in early vision, improving the perception of chromatic luminance changes the neural activation of the visual cortex. Furthermore, cognitive processing makes low or minimal contributions to the resulting VEP. Therefore, goggle VEP testing can provide solid evidence of the effect of visual rehabilitation. Two to three similar online VEP waveforms were used to ensure that the data were reliable and stable. The waveform and latency of P100 were demonstrated.

Data Analysis

We primarily used visual analysis of graphic displays of data. Level and trend were also assessed during inspection of the characteristics of within-phase and between-phase data. Level was computed by the mean of all data points within a phase, and trend was demonstrated by a celeration line, which demonstrates a trend as accelerating or decelerating, to characterize rate of change (Portney & Watkins, 2000).

Results

The subject completed this visual rehabilitation project in 3 mo. Although he attended all the sessions, he was unable to finish the comprehensive evaluations for one session because of emotional problems. Possibly because the training programs were carried out in conjunction with play activities whenever possible, the child’s parents reported no apparent adverse effects.

Chromatic Luminance Discrimination

Mean correct responses for chromatic luminance discrimination ranged from 9.3 (standard deviation [SD] = 3.1) to 14.0 (SD = 1.4) for baseline sessions, 13.3 (SD = 1.2) to 17.8 (SD = 0.4) for intervention sessions, and 12.0 (SD = 0.0) to 17.5 (SD = 1.0) for follow-up sessions. Mean response time for chromatic luminance discrimination ranged from 3,163 ms (SD = 409 ms) to 3,808 ms (SD = 931 ms) for baseline sessions, 2,053 ms (SD = 700 ms) to 1,602 ms (SD = 683 ms) for intervention sessions, and 1,871 ms (SD = 455 ms) to 1,263 ms (SD = 231 ms) for follow-up sessions. Visual analysis of all data points, level of mean, celeration lines for correct response scores, and response times are illustrated in Figure 2 and Figure 3. During the intervention phase, the subject demonstrated consistent improvement in discriminating the color red. As indicated by visual analysis and levels of mean, the participant also improved in discriminating the colors green and yellow, but celeration lines did not support gains in green and yellow color perception. Furthermore, the variability of data points for baseline phases of discriminating green and yellow was large. The child’s performance in discriminating green and yellow demonstrated greater stability during the intervention and follow-up phases, however. After withdrawal of perception training, visual analysis confirmed a decrease in performance for red, yellow, and green discrimination.

Regarding response time for chromatic luminance discrimination, visual analysis, levels of mean, and celeration line methods all supported obvious decreases in response time in intervention phases. After intervention withdrawal, response times in the follow-up phases increased but remained less than that of baseline phases.

Visual Fixation

Mean total fixation time was 8.4 s (SD = 5.4 s) for the baseline sessions and increased to 21.0 s (SD = 8.1 s) for the intervention sessions. Mean maximum fixation time was 4.6 s (SD = 4.0 s) for the baseline sessions and improved to 8.2 s (SD = 3.7 s) for the intervention sessions. Figure 4 depicts the collected data on fixation times. Visual analysis, level of mean, and celeration line all demonstrated an apparent improvement in total fixation time but not in maximum fixation time. The mean maximum fixation time increased slightly after visual fixation training.

Goggle VEP Test

Figures 1A and 1B show the waveforms and latencies of the goggle VEPs before and after visual rehabilitation. In line with the visual behavioral results, visual rehabilitation produced positive changes in early cortical neural activation. Before visual rehabilitation, only a small and delayed waveform (P100 = 142 ms), similar to the P100 wave, was recorded during the goggle VEP test. The waveform was poorly reproducible with small amplitude. A better waveform with shortening of the P100 wave was recorded after visual rehabilitation, although no delayed cortical response after P100 was noted (P100 = 110 ms).

Discussion

Although several studies have supported the efficacy of a remedial approach for children with visual impairment
Few studies have examined the effect of visual training in children in middle childhood with severe visual impairment. In this study, we demonstrated that intensive contrast perceptual training and oculomotor training could improve residual visual function in a 6-yr-old child with severe congenital visual problems in the anterior visual pathway. This process was not intended to change the function of the anterior visual pathway but rather to increase the neural adaptation of the whole brain to specially designed visual training programs and thereby improve visual behaviors (Good et al., 2001; Hamamé, Cosmelli, Henriquez, & Aboitiz, 2011; Sasaki et al., 2010).

Besides the amelioration of chromatic luminance discrimination and fixation time, this child also had some improvement in visual acuity and functional mobility. Visual acuity was assessed using a modified nonparametric visual acuity test developed for children with visual impairment to...
evaluate visual development and visual progress after visual training (Sonksen et al., 1991). Regarding near acuity, the child could detect a white styrofoam ball with a 4-cm diameter at a 20-cm distance against a black background before the study, and his near acuity did not change after training. As for distance acuity, before the study the child had some difficulty in detecting a waving adult body at a distance of 0.75 m. After the study, however, he was able to detect adult hand waving at 0.75 m. This indicated that he was better able to detect large objects with motion attributes at a far distance. This finding was also compared with the child’s change in orientation and mobility ability.

In our previous clinical experience, children with severe visual impairment could navigate more efficiently when their contrast discrimination abilities improved; this finding is consistent with the experience of other clinical therapists (Lueck, 2004). During this study, we regularly observed how the child moved around the campus. Before the study, he did not combine any visual cues with mobility. Near the end of this study, he began to actively

Figure 3. Mean response times for (A) red, (B) yellow, and (C) green chromatic luminance discrimination during the baseline, intervention, and follow-up phases.

Note. A1 = notreatment baseline phase; B = treatment phase of chromatic luminance discrimination training; A2 = follow-up phase.
notice differences in contrast in his school environment, according to reports from his mother. He also began to change his behavior patterns in the orientation and mobility training. He not only used the information from his hearing and long cane but also noticed a large obstacle before the long cane touched it. In other words, he started to use his newly learned visual skills to adapt to the environment and move around more efficiently.

The goggle VEP testing also provided electrophysiological and objective support for the training effect. Goggle VEP testing is used to evaluate the integrated response to flash stimulation in the primary visual cortex. The latency and amplitude of the P100 wave are an indicator of visual conduction efficacy and capacity. A shortened and prominent P100 wave implies improvement of the efficacy and capacity of the visual cortex response after visual rehabilitation. We suspect that the primary visual cortex may have received increased visual stimulation under this specially designed program and became more active after the training. We also suspect that this effect may build on the processes of bottom-up and top-down interactions (Sagi, 2011). Therefore, selecting the type of visual stimuli and controlling the factors related to top-down processing are equally important. Moreover, the greater activity in the visual cortex may have increased focal blood perfusion and improved brain maturation in this young child.

In the early sessions of the intervention phase, the child’s ability to discriminate red chromatic luminance from green and yellow chromatic luminance improved rapidly, and he reached the ceiling scores. One possible reason is that the luminance of the red was lower than that of the green and yellow, so the child could more easily discriminate red from green and yellow. Because of the ceiling effect, the scores of correct responses for red might not reflect a true visual training effect. However, the average response time continually decreased from 3,808 ms (baseline phase) to 1,602 ms (intervention phase), and this improvement lasted into the follow-up phase, indicating that the subject could manage and process the visual information more efficiently.

Response time has meaning and importance in clinical situations and is used to monitor recovery and predict further outcomes (Felmingham, Baguley, & Green, 2004; Van Zomeren & Deelman, 1978). In addition, because most environmental information is presented in a time-limited fashion, successful transfer and adaptation of the results of visual training into everyday tasks is also dependent on time-limited response (Owsley, Sloane, McGwin, & Ball, 2002). Therefore, the improvement in response time of chromatic luminance discrimination was an important measure of the effect of visual rehabilitation. The more response time decreased, the more opportunities the child had to adopt the newly developed perceptual ability into his real life.

For the visual fixation part, the child had more apparent improvement in total fixation time than in maximum fixation time after 10 treatment sessions. He had a greater capacity to consciously control his oculomotor systems to locate a target, but he still had difficulty maintaining fixation on that target. The increase in total fixation time was still clinically significant, however. According to the parents’ and researcher’s observations, after this study the child was better able to precisely detect large obstacles with high to moderate contrast and avoid them during navigation. Therefore, he combined the newly developed abilities of oculomotor control and contrast discrimination with his orientation and mobility skills to increase his functional performance.

In this study, we did not directly train the subject’s functional performance, but he did show some improvement in orientation and mobility. The major reason may be that he had practiced contrast discrimination extensively in play patterns. We designed several different artificial situations to enable the child to practice this skill, such as tracking a toy with light in a dim room or following a big reflective plate to find a stuffed animal’s home in a naturally
lit room. Therefore, having acquired a stable ability to discriminate the contrast between two large objects or the contrast between object and background in a familiar environment, he could be guided by contrast information and knowledge about the environment to choose the direction of mobility. Thus, we believe that task-based intensive visual training led to functional gains in this child.

The training materials and instruments used in this study were easy to obtain and inexpensive. Therefore, these programs and concepts could easily be incorporated into occupational therapy clinical practice. We suggest that the most important considerations are to analyze the subject’s visual functions, predict what these visual functions could do in further functional activities, and design corresponding visual training programs to enhance these visual skills.

**Implications for Occupational Therapy Practice**

The necessity and possibility of visual rehabilitation for people with severe visual impairment have been questioned by ophthalmological and rehabilitation specialists. The results of this single case study, however, demonstrate a positive visual response and functional change after intensive and systematic training for a child with severe anterior visual pathway lesions. We provide the following recommendations for current occupational therapy practice:

- Children with severe visual impairment still have residual visual functions. Experience-dependent plasticity from intensive visual training can be promoted in children with severe anterior visual pathway lesions even beyond the traditional visual critical periods, especially in the case of children who have only visual problems.
- The underlying theoretical framework involves visual neuroscience, visual development, specific visual characteristics in children with severe visual impairment, and the correlation between visual components and functional visual performance.
- Contrast sensitivity and oculomotor control are important visual elements for children with severe visual impairment. Children who are more sensitive to contrast and who accurately control eye movement are likely to be better at detecting large objects and to benefit from magnification of objects.
- The properties of training materials include the size and brightness of objects, contrast between target objects and other objects, contrast between objects and surroundings, and environmental luminance.
- Training programs that integrate play activities and conform to children’s cognitive abilities are suggested to encourage active participation.
- Training 2×/wk for 40–50 min each session is suggested.
- Children’s visual behavior and psychological response to training should be carefully observed to avoid overtraining, which can cause fatigue and emotional upset.

**Limitations and Further Research**

Several limitations of this study need to be considered. First, only one child was studied, so the applicability of the research data is limited. Second, although contrast discrimination is a major issue in this study, no standardized test was used to assess contrast sensitivity specifically; we used the ability to discriminate color luminance to represent his contrast sensitivity. Thus, we could not provide clearer information about this child’s contrast sensitivity. Third, because of the lack of a functional measure or systematic observation to evaluate his functional changes, we could not report more comprehensive and quantitative results in the functional area. Finally, we did not arrange long-term follow-up to assess how long the effects persisted. Although this is a single case study, the promising results warrant larger-scale studies with functional visual assessment and long-term follow-up to demonstrate the benefits of visual rehabilitation for children’s visual function.

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**References**


