· Clinical Research ·

Effect of visual perception training on binocular visual function reconstruction in patients after strabismus surgery

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Abstract
● **AIM:** To explore the effect of visual perception learning software training (VPT) on binocular visual function reconstruction in children with intermittent exotropia after strabismus surgery.
● **METHODS:** Ninety children with intermittent exotropia admitted to our hospital from June 2018 to December 2018 were included, and randomly divided into VPT and control groups. Children in the control group received basic binocular vision training, while those in the VPT group received VPT after strabismus surgery. Tertiary visual function, visual perception function, Newcastle Control Score (NCS), and ocular position retraction rate were compared at 3 and 12mo after the surgery.
● **RESULTS:** At 3 and 12mo after the surgery, the proportion of simultaneous perception, binocular fusion version and binocular stereo vision in the VPT group was conspicuously higher than that in the control group ($P<0.05$). After the vision training, the binocular visual perception functions of children in both groups were significantly improved compared with that before training ($P<0.05$). Interestingly, the grating sharpness, texture perception and texture motion perception in the VPT group were dramatically better than control group ($P<0.01$). The NCS in the VPT group was significantly lower than that in the control group ($P<0.05$). The ocular position retraction rate in the VPT group was significantly lower than that in the control group at 12mo (8.89% *vs* 26.67%, $P=0.03$).
● **CONCLUSION:** VPT effectively promotes binocular visual function reconstruction in intermittent exotropia children after strabismus surgery and reduces the strabismus severity and ocular position retraction rate.
● **KEYWORDS:** children; intermittent exotropia; visual perception training; ocular position; binocular visual function
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INTRODUCTION
Intermittent exotropia occurs in children at the age of 3-10y, which is a type of exotropia between exophoria and strabismus, accounting for about 8% of exotropia[1]. The main clinical symptom of children with intermittent exotropia mainly is photophobia[2]. Intermittent exotropia is progressive and usually present when viewed from a distance in the initial phase. If it is not treated in time, intermittent exotropia will lead to prolonged course of the disease, increased strabismus frequency and visual fatigue, affect normal visual development, and eventually develop into persistent exotropia, and even cause certain visual impairment[2-3]. This will bring great pain and burden to the physical and mental health of children and affect their families[4-5]. Therefore, early and correct correction treatment of intermittent exotropia is very important for children's normal visual development.

At present, strabismus surgery is one of the main treatment methods for strabismus, which can effectively correct the eye position and keep the binocular visual axes parallel. However, the triple visual function of children is not yet fully developed. Surgical correction of eye position only corrects strabismus anatomically but does not completely recover to the normal binocular vision function.

Moreover, strabismus can lead to the triple visual dysfunction in children, and even loss of triple visual function before the surgery. There is also a high recurrence rate of strabismus after the surgery[6]. Therefore, the implementation of visual function reconstruction training after the surgery is important in the process of strabismus correction and treatment.

The traditional treatment of binocular visual function recovery is synoptophore training, which is expensive, complicated to operate and boring to train, making difficulty to popularize[7]. In recent years, visual perception learning software training (VPT) developed by using the principle of brain neural plasticity has been introduced into the field of strabismus treatment, and attracted the wide attention[8]. Therefore, the purpose of this study was to explore the effect of VPT on binocular visual function reconstruction in children with intermittent exotropia after strabismus surgery.

SUBJECTS AND METHODS

Ethical Approval This study was approved by the Medical Ethics Committee of Anhui Provincial Children's Hospital (2019SEY008). Guardians of all children have signed informed consent forms.

Subjects Ninety children with intermittent exotropia admitted to Anhui Provincial Children's Hospital from June 1, 2018 to December 31, 2018 were included in this retrospective study. Patients were divided into VPT group (n=45) and control group (n=45). Inclusion criteria[9]: 1) all patients were diagnosed as intermittent exotropia on admission; 2) strabismus degree of both eyes was $\geq 20^{\Delta}$; 3) the best corrected vision of both eyes was ≥0.5. Exclusion criteria: 1) other types of strabismus; 2) high myopia, hyperopia or astigmatism; 3) combined with ocular diseases such as collective paralysis and nystagmus; 4) previous history of strabismus treatment or intraocular surgery; 5) unable to cooperate with training; 6) the follow-up data were incomplete.

Postoperative Binocular Visual Function Recovery Training After strabismus surgery, children in the control group received basic binocular vision training, including aggregation ball, aggregation card and free space fusion card, which were guided by professional doctors. Children received training twice a day for 15min each time. The training lasted for 3mo. Children in the VPT group received VPT for binocular visual function recovery training. The system automatically generated the targeted and personalized training programs according to the information of children's vision, diopter, eye position, eye movement and triple visual function. The training contents included deinhibition training, fusion function training, stereo vision function training, visual skill training and contrast sensitivity training. Depending on the child's visual function from the first grade to the third grade, the training also ranged from simple to complex. Children received training twice a day for 15min each time. The training lasted for 3mo. Children received training at home or in hospitals. During the training process, doctors dynamically adjust the training plan through real-time monitoring in the background of the system.

Definition 1) Simultaneous vision: the ability of both eyes to gaze and perceive at the same time, which belongs to the primary visual function. Without simultaneous vision, there can be no fusion function and stereo vision. 2) Binocular fusion version: based on the normal simultaneous perception of both eyes, through the analysis and processing of the brain, the two effects of slightly different retinas of the two eyes are integrated into a complete object image, which belongs to the secondary visual function. 3) Binocular stereo vision: stereo vision belongs to the third level of visual function, which is the feeling that the eye can distinguish the shape of objects near and far when observing the scene. On a three-dimensional level, objects are three-dimensional, not just flat as photographs. 4) Grating sharpness: mainly testing the vision in bright environments. 5) Texture perception: mainly the ability to distinguish texture information. 6) Textured motion perception: the ability to distinguish between motion visual information.

Outcome Measures 1) Visual function was assessed by observing changes in the simultaneous vision, fusion vision, and stereo vision of children. The higher the value, the higher the degree of recovery of the visual function of the patient. 2) Strabismus: After monocular occlusion for 1h, prism occlusion test was performed. The tip of the prism was outward, and the horizontal plane is perpendicular to the axis of vision. Children looked at visual targets at 6 m and 33 cm, alternately covering their eyes until the eye position was completely neutralized. The values were record. 3) Titmus stereogram was used to examine the triple visual functions. 4) Newcastle Control Score (NCS)[10]: The NCS was used to assess the control ability. The control scale consisted of three parts, family score, clinical distance vision score and near vision score. Family scores were provided by parents according to daily life observation. The clinical distant and near scores were recorded by the same senior physician.

Statistical Analysis SPSS25.0 software was used to analyze all statistical data. The counting data were expressed as n (%), and the difference between two groups was evaluated by χ^2 test. The measurement data were expressed as mean±standard deviation (SD), and t-test was used for comparison between two groups. $P<0.05$ suggested that the difference was statistically significant.

RESULTS

General Clinical Information The strabismus degree was 52.05±18.02 and 51.56±17.87 prism degrees in the control and VPT groups, respectively (P=0.887). There were no significant differences in the preoperative triple visual functions (simultaneous perception, binocular fusion version, and binocular stereo vision) between two groups (P>0.05; Table 1). Moreover, there was also no significant difference in

Table 1 General data of two groups

Parameters	VPT group (*n*=45)	Control group (*n*=45)	χ^2/t	*P*
Gender, *n* (%)			0.178	0.673
Male	24 (53.33)	22 (48.89)		
Female	21 (46.67)	23 (51.11)		
Age (y), mean±SD	6.85±3.22	7.05±3.40	0.802	0.423
Strabismus degree, mean±SD	$51.56^{\Delta}\pm17.87^{\Delta}$	$52.05^{\Delta}\pm18.02^{\Delta}$	0.130	0.887
Triple visual functions, *n* (%)				
Simultaneous vision	14 (31.11)	15 (33.33)	0.051	0.822
Binocular fusion vision	8 (17.78)	9 (20.00)	0.073	0.788
Binocular stereo vision	5 (11.11)	4 (8.89)	0.123	0.725
Postoperative ocular positional rate, *n* (%)	44 (97.78)	43 (95.56)	0.345	0.557

VPT: Visual perception learning software training.

Table 2 Triple visual function reconstruction in two groups

Triple visual function	VPT group (*n*=45)	Control group (*n*=45)	χ^2	*P*
Preop.				
Simultaneous perception	14	15	0.051	0.822
Binocular fusion version	8	9	0.073	0.788
Binocular stereo vision	5	4	0.123	0.725
Postop. 3mo				
Simultaneous perception	33	27	1.800	0.180
Binocular fusion version	29	18	5.388	0.020
Binocular stereo vision	26	16	4.464	0.036
Postop. 12mo				
Simultaneous perception	39	32	3.269	0.071
Binocular fusion version	35	35	5.000	0.025
Binocular stereo vision	35	24	5.954	0.015

VPT: Visual perception learning software training.

Table 3 Binocular visual perception in two groups before and after training

Groups	*n*	Grating sharpness		Texture perception		Texture motion perception	
		Before training	After training	Before training	After training	Before training	After training
VPT group	45	2.34±1.03	4.70 ± 1.09^{a}	2.93±1.01	5.10 ± 1.22^{a}	3.19±1.04	5.00 ± 1.78^{a}
Control group	45	2.45±1.02	3.54 ± 1.12^{a}	2.88±0.98	4.09 ± 1.19^{a}	3.22±1.05	4.14 ± 1.25^{a}
t		0.509	5.465	0.238	3.976	0.136	2.652
P		0.612	0.000	0.812	0.000	0.892	0.001

VPT: Visual perception learning software training. $^{a}P<0.05$ compared with before training.

the postoperative ocular positional rate between the two groups (95.56% *vs* 97.78%, $P>0.05$; Table 1).

Triple Visual Function Reconstruction There were no significant differences in preoperative triple visual functions between two groups ($P>0.05$). At 3 and 12mo after strabismus surgery, simultaneous vision, fusion vision, and stereo version were effectively reconstructed in both groups, which were significantly better than those before surgery ($P<0.05$). Fusion vision and stereo vision in the observation group were significantly better than those in the control group ($P<0.05$; Table 2).

Binocular Visual Perception Functions There were no significant differences in binocular visual perceptions between two groups before training ($P<0.05$; Table 3). After training, the binocular visual perception functions in both groups were significantly improved compared with that before training ($P<0.05$; Table 3). Interestingly, the average levels of grating sharpness, texture perception and texture motion perception in the observation group mostly reached the normal levels, which were dramatically higher than those in the control group (t=5.465, 3.976, and 2.652, all $P<0.01$; Table 3).

NCS Changes Before and After Training There was no significant difference in NCS between two groups before training ($P>0.05$). After training, the NCS in two groups were significantly lower than those before training ($P<0.05$), and the NCS in the observation group were significantly lower than that in the control group (t=3.888, $P<0.01$; Table 4).

Ocular Position Regression Rate at 12mo after Operation

Table 4 NCS in two groups before and after training

Groups	*n*	Before training	After training
VPT group	45	2.93±0.71	1.09±0.23[a]
Control group	45	3.02±0.76	1.30±0.28[a]
t		0.581	3.888
P		0.563	0.000

VPT: Visual perception learning software training; NCS: Newcastle Control Score. [a]$P<0.05$ compared with before training.

At 12mo after operation, the ocular position retraction rate in the VPT group was 8.89%, which was significantly lower than that in the control group (26.67%, $\chi^2=4.86$, $P=0.03$).

DISCUSSION

Visual function describes the function of eyes and basic visual system in detecting a target stimulus[11]. Low-level visual function represents the elementary features, such as the location, luminance or contrast, mediated by brain areas including retina for sensation of light, optic nerve for secondary visual neurons, superior colliculus for low-level localization and saccade initiation and V1 for processing of simple shapes[11-14]. High-level visual function is the cognitive processes responsible for perception of object recognition, size, distance, color and shape, and detection of motion[15], which ensures the relative position between ourselves and the environment[16]. Stereo vision is the most advanced visual function[17]. Strabismus surgery can effectively correct the eye position, which only provides eye position conditions for the reconstruction of visual function, but does not achieve functional cure. The reconstruction and recovery of stereoscopic vision function are also the goal of clinical strabismus treatment.

Some studies have shown that intermittent exotropia occurs later than other type strabismus[18-19]. After strabismus surgery, the binocular vision function develops better, and is easier to recover and reconstruct binocular vision function. However, there is still a high risk of recurrence without targeted training. A previous study has shown that, after strabismus surgery, the eye position return rate without any intervention is as high as 54.8%[20]. In this study, children with intermittent exotropia in the control group received basic binocular vision training, and the eye position return rate was still as high as 22.22% at 12mo after strabismus surgery. Therefore, the clinical attention still focuses on the further improvement of the visual function training methods for children after strabismus surgery.

In recent years, the formation process and mechanism of vision in cerebral cortex center have been deeply studied[21]. A large number of studies have shown that the formation of stereo vision requires not only the coordination of both eyes, but also the fine and complex processing of cerebral cortex, in which visual perception plays an important role[22-23]. In addition, the visual perception function of brain nervous system is plastic[24]. Targeted visual stimulation and training can effectively activate the related visual signal pathways in cerebral cortex and reshape the visual processing ability of central system, which provides a theoretical basis for visual perception learning[25].

At present, the concept of VPT has been gradually applied to clinical practice, especially in the treatment of amblyopia[26]. Compared with traditional training methods, the VPT has three advantages. First, the VPT is perfect and advanced visual training methods, including eye movement training, saccade training, gathering and dispersing training, jumping gathering and dispersing training, visual memory training, *etc*. The effective training programs can be intelligently and accurately designed according to the specific conditions of each child. Second, the VPT is interesting with less compliance, which is the main reason for the reduction of the training effect of traditional training methods. The system adopts advanced computer animation technology and has rich multimedia resources. By combination with the age and hobbies, the children complete the training in the competition, and the treatment compliance is significantly improved. In addition, the software is perfectly linked to internet, allowing each child to train in the hospital or at home, which is a great help for the continuity of the training. Third, doctors can monitor the child's training in real time from the background of the system, and dynamically adjust the training plan to make the training more targeted and effective.

The results of this study have shown that VPT is significantly effective for the reconstruction of visual function in children with intermittent exotropia after strabismus surgery. Compared with the control group, the children in the VPT group have a higher proportion of fusion visual function and stereoscopic visual function reconstruction, and the visual perception function and NCS have improved more obviously at 3 and 12mo after strabismus surgery. Meanwhile, the eye position regression rate is significantly reduced. Those results are consistent with a previous research[27].

In conclusion, VPT has a significant effect on the reconstruction of binocular visual function in children with intermittent exotropia after strabismus surgery. Because children have good compliance, VPT is worthy of clinical application.

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