• Clinical Research •

Add-on perceptual learning on refractive amblyopia in children

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Abstract

● **AIM:** To evaluate the visual outcomes of standard amblyopic treatment add-on training *via* perceptual learning in refractive amblyopic children and to identify the risk factors for treatment failure.

● **METHODS:** Retrospective charts were reviewed in children with refractive amblyopia who received standard treatment and add-on Cambridge Visual Stimulator (CAM) training. The add-on CAM group that was enrolled had worn full-corrected glasses for at least 2mo before training. A control group received only the standard treatment. Treatment success was defined as best-corrected visual acuity (BCVA) ≥20/25. The age, sex, initial BCVA, refractive errors, sessions and duration of training, and final BCVA were recorded.

● **RESULTS:** A total of 209 children (129 children in add-on CAM group and 80 children in control group) were enrolled. Seventy-six percent of unilateral and 87% of bilateral amblyopic children achieved treatment success. In children with unilateral or bilateral moderate amblyopia, the duration to reach BCVA ≥20/25 was significantly shorter in add-on CAM group than in control group. Poor initial BCVA (P<0.001) and high astigmatism (P=0.007) were risk factors for treatment failure after add-on CAM training. Age, sex, and types of refractive error were not associated with treatment success.

● **CONCLUSION:** Add-on CAM training is an effective strategy for visual improvement and can shorten the treatment course when the effect of standard treatment is limited in amblyopic children.

● **KEYWORDS:** amblyopia; amblyopic children; add-on Cambridge Visual Stimulator training; astigmatism

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INTRODUCTION

Amblyopia, which is the most common cause of preventable visual loss in children, is an important public health issue throughout the world[1-2]. Clinically, amblyopia is defined as the unilateral or bilateral decrease in best-corrected visual acuity (BCVA) caused by inadequate visual input in the early period of life without anatomical abnormalities being present in the eye or visual pathway. The prevalence of amblyopia is estimated to be 0.7% to 6% of children worldwide[1,3-4]. According to the causes of the disorder, amblyopia can result from strabismus, refractive errors, and visual deprivation[5].

Amblyopic treatment is of importance because it could affect the visual attention and visuo-cognitive ability in children[6]. At present, the standard treatment for amblyopia includes the clearing of the visual axis, correction of refractive errors, occlusion of the fellow eye and encouragement of the visual stimulation by using near-work training devices[7-11]. After standard treatment, although 73%–90% of amblyopic children exhibit visual acuity (VA) improvements, 15%–50% of amblyopic children cannot achieve optimal vision even after extended periods of treatment[12-14]. Several studies have reported that factors such as initial BCVA, interocular difference of BCVA, causes of amblyopia, duration of abnormal vision, age at which the treatment was initiated, compliance with treatment, and dose of occlusion may be correlated with treatment responses[15-18].

The Cambridge Visual Stimulator (CAM), which is the first application of perceptual learning theory, is conducted by passively viewing high-contrast rotating gratings and was shown to be effective by Campbell *et al*[19] in 1978. In unilateral amblyopia, the effect of CAM training was favorable but nonsuperior to conventional occlusion therapy, which limited its application to amblyopic children[20]. However, it is not clear as to whether the rate of VA improvement and final VA of conventional occlusion therapy add-on CAM training is better than occlusion therapy alone in amblyopic children. Our previous study showed that CAM treatment was effective for bilateral amblyopia to achieve satisfactory improvement in VA within 3mo[21]. Moreover, few studies have demonstrated the clinical course and visual outcome after standard treatment add-on CAM training on both unilateral and bilateral amblyopia. Therefore, the purpose of this study was to evaluate whether add-on CAM training accelerates VA improvement and promotes better visual outcomes after standard treatment in amblyopic children and to analyze the risk factors associated with poor responses to amblyopic treatment.

SUBJECTS AND METHODS

Ethical Approval The study was approved by the institutional Review Board of Chang Gung Medical Foundation (IRB number: 202101080B0C502). The informed concent was obtained from the subjects.

Participants Children aged between 4 and 9y at the first visit who received amblyopic treatment in Kaohsiung Chang-Gung Memorial Hospital from January 2015 to December 2019 were enrolled in this study. The charts of consecutive patients presenting with amblyopia and completing a minimum follow-up of 6mo were reviewed. The inclusion criteria included amblyopic children with BCVA at a distance worse than 20/25 *via* Landolt C chart, the presence or history of refractive errors, anisometropia, and having worn full-corrected spectacles for at least 2mo for refractive errors. Children in the control group received only standard amblyopic treatment, such as full-corrected spectacles and/or patching therapy. The distribution of children to the control group was patients that could not or refused to join the perceptual learning program. Children who did not complete the ophthalmological exams or had any types of strabismus, ocular structural abnormalities, learning difficulties, developmental delays, or coexisting systemic diseases were excluded from the analysis.

Ophthalmological Examinations and Amblyopia Grouping The data of complete ophthalmological examinations, including cycloplegic refraction after the application of 1% tropicamide three times in each eye at 10min apart, BCVA using the Landolt C chart, slit-lamp examination, dilated fundoscopy, and motility test, were recorded. Full-corrected spectacles were prescribed for all the patients to achieve the best VA. Based on the difference in initial BCVA between the two eyes, unilateral amblyopia was defined as an initial BCVA <20/25 in the lesion eye and >2 lines of interocular difference, whereas bilateral amblyopia was defined as a BCVA <20/25 in both eyes and no interocular difference of two lines. For the statistical analysis of VA in the bilateral subtype, only the worse eye or the right eye (if these eyes were the same) was included in the data analysis. Due to the fact that the major cause of amblyopia involved refractive errors, we subdivided refractive amblyopia into hypermetropia (spherical power >+3.0 D), myopia (spherical power <-4.0 D), and astigmatism (cylinder power ≤-1.5 D)[22]. The spherical equivalent (SE) was defined as the sum of the spherical power with half of the cylinder power.

Add-on amblyopic trainings with perceptual learning by CAM and cheiroscope In the add-on CAM training group, all of the patients had worn their spectacles to correct refractive errors for at least 2mo before initiating the amblyopic training. For unilateral amblyopia, the patching prescription followed the protocol of the Pediatric Eye Disease Investigator Group (PEDIG) studies according to initial BCVA[23]. The patching regimens were conducted at 2h per day for mild (20/40 to 20/25) and moderate (20/80 to 20/40) amblyopia and at 6h per day for severe amblyopia (20/400 to 20/100). The duration of the patching therapy was tapered after the patient achieved improvement in VA. The amblyopic training program consisted of two parts including CAM and cheiroscopy. The training was binocular in cheiroscope and monocular or binocular in CAM depended on unilateral or bilateral amblyopia. The children did not make other training at home in our study population. The program was held at weekly interval and technicians were at the side of the patients for instruction and encouragement if necessary. One session of training lasted for 15–30min depending on the concentration and capability of the children. During CAM training, the patients chose the three high-contrast square waves and smallest discernible gratings[19]. Each grating was rotated at one revolution per minute behind a clear acrylic glass cover on which the children drew pictures of animals or cartoon characters under supervision. Before or after the CAM training, cheiroscope training was performed. The cheiroscope consisted of a drawing pad and a viewing instrument for blending an image into view over the drawing. The children used a pencil to trace the target and draw the pictures in a binocular manner. After each session of training, the BCVA was measured. Treatment success was defined as a BCVA that reached 20/25 or better; otherwise, treatment failure occurred. The number of sessions to achieve treatment success, the total duration of the training course, and the final BCVA at 6mo were recorded. For those individuals who did not have treatment success, we recorded the numbers of

Table 1 Demographic data of the add-on CAM training and control patients in lesion eyes

Parameters	Unilateral amblyopia			Bilateral amblyopia		
	Add-on CAM (*n*=66)	Control (*n*=51)	*P*	Add-on CAM (*n*=63)	Control (*n*=29)	*P*
Age (y, mean±SD)	5.32±1.08	4.78±0.83	0.004	5.02±1.04	4.55±0.95	0.044
Gender (*n*, M/F)	32/34	23/28	0.716	29/34	15/14	0.612
Initial BCVA (logMAR, mean±SD)	0.51±0.28	0.39±0.34	0.041	0.43±0.27	0.38±0.19	0.386
Depth of amblyopia (Initial BCVA)			0.006			0.570
Severe (<20/100)	7 (11%)	3 (6%)		6 (9%)	1 (3%)	
Moderate (≥20/100 and ≤20/40)	49 (74%)	27 (53%)		39 (62%)	20 (69%)	
Mild (>20/40)	10 (15%)	21 (41%)		18 (29%)	8 (28%)	
Refractive errors (n)			0.178			0.770
Hypermetropia	14 (21%)	18 (35%)		6 (10%)	1 (3%)	
Myopia	2 (3%)	1 (2%)		2 (3%)	1 (3%)	
Astigmatism	48 (73%)	28 (54%)		50 (79%)	24 (83%)	
Astigmatism only	24	13		22	13	
Hypermetropia+astigmatism	11	11		19	9	
Myopia+astigmatism	13	4		9	2	
Final BCVA at 6mo (logMAR, mean±SD)	0.12±0.22	0.01±0.04	<0.001	0.06±0.20	0.02±0.05	0.090
Treatment success	50 (76%)	48 (94%)	0.008	55 (87%)	27 (93%)	0.406

BCVA: Best-corrected visual acuity; CAM: Cambridge Visual Stimulator; SD: Standard deviation.

sessions and duration needed to reach the final BCVA instead of total training sessions.

Statistical Analysis Descriptive statistics (means, standard deviations, and percentages) were computed for the demographics and clinical variables. The BCVA checked by the Landolt C chart was converted to logarithm of the minimum angle of resolution (logMAR) for the statistical analysis. The treatment effects of add-on amblyopic trainings, including the number of sessions, the duration needed to achieve a BCVA ≥20/25, and the final BCVA at 6mo, were analyzed by using a repeated measures analysis of variance and independent *t* test, compared with the control group. To explore the risk factors for treatment failure in unilateral or bilateral subtypes, the parameters of sex, age at initiation of amblyopic training, refractive errors, and initial BCVA in the successful treatment (final BCVA ≥20/25) group were compared with those in the treatment failure (final BCVA <20/25) group *via* the Chi-square test or independent *t* test. A *P* value of less than 0.05 was considered to be statistically significant.

RESULTS

A total of 209 children met the inclusion criteria and participated in amblyopic treatment. The add-on CAM training group included 66 unilateral and 63 bilateral amblyopic children. Eighty children were in the control group, with 51 children in the unilateral classification and 29 children in the bilateral amblyopia classification. The demographic data were shown in Table 1. The mean age at the initiation of trainings was significantly older in the add-on CAM training group than in the control group (5.32±1.08y *vs* 4.78±0.83y, *P*=0.004 unilaterally, and 5.02±1.04y *vs* 4.55±0.95y, *P*=0.044 bilaterally).

In the unilateral amblyopia group, the mean initial logMAR BCVA of lesion eyes in the add-on CAM training group (0.51±0.28) was significantly poorer than that in the control group (0.39±0.34; *P*=0.041). Fifty-six (85%) children in the add-on CAM training group had moderate and severe amblyopia, which was significantly more than the control group (59%; *P*=0.006). Most amblyopic eyes involved astigmatism (73% in the add-on CAM training group, 54% in the control group). The refraction of 2 eyes in the add-on CAM training group and 4 eyes in the control group did not meet our grouping criteria. At 6mo, the mean final logMAR BCVA in the add-on CAM training group (0.12±0.22) was also significantly poorer than that in the control group (0.01±0.04; *P*<0.001). The percentage of amblyopic eyes acquiring treatment success (final BCVA ≥20/25) was seventy-six percent (50/66) in the add-on amblyopic training group, which was lower than that in the control group (94%; *P*=0.008).

In bilateral amblyopia, the mean initial logMAR BCVA did not differ between the add-on CAM training group (0.43±0.27) and the control group (0.38±0.19; *P*=0.386). Forty-five (71%) children in the add-on CAM training group had moderate and severe amblyopia, which was similar to the control group (72%; *P*=0.57). Moreover, astigmatism was the most common refractive error in amblyopic children in both groups (79% in the add-on CAM training group, 83% in the control group). At 6mo, there was no significant difference in the final BCVA between the add-on CAM training group and the control group

Table 2 The visual outcomes in moderate unilateral and bilateral amblyopia with add-on CAM training and control mean±SD

Parameters	Moderate unilateral amblyopia			Moderate bilateral amblyopia		
	Add-on CAM (*n*=49)	Control (*n*=27)	*P*	Add-on CAM (*n*=39)	Control (*n*=20)	*P*
Age (y)	5.39±1.04	4.93±0.87	0.054	4.77±1.01	4.55±1.05	0.440
Initial BCVA (logMAR)	0.49±0.14	0.43±0.14	0.793[a]	0.45±0.13	0.43±0.12	0.854[a]
Final BCVA at 6mo (logMAR)	0.08±0.11	0.01±0.03		0.04±0.07	0.01±0.05	
Treatment success	39 (79.6%)	26 (96.3%)	0.085	34 (87.2%)	19 (95.0%)	0.653
Duration to reach BCVA ≥20/25 (wk)	10.08±8.24	22.67±13.24	<0.001	12.21±7.40	32.31±24.41	0.002
Final BCVA ≥20/30	41 (83.7%)	27 (100.0%)	0.045	36 (92.3%)	19 (95.0%)	1.000
Improvement of VA ≥3 lines (0.3 logMAR)	42 (85.7%)	27 (100.0%)	0.046	37 (94.9%)	19 (95.0%)	1.000

BCVA: Best-corrected visual acuity; CAM: Cambridge Visual Stimulator; SD: Standard deviation; VA: Visual acuity. *P* value for Chi-square test or two independent *t* test. [a]*P* value for repeated measures analysis of variance.

(*P*=0.090). The percentage of amblyopic children acquiring treatment success did not differ between the add-on CAM training group (87%) and the control group (93%; *P*=0.406).

Effect of Add-on CAM Training in Moderate Amblyopia The visual outcomes in moderate unilateral and bilateral amblyopia with add-on CAM training and the control treatment are shown in Table 2. In moderate unilateral amblyopia, there were no significant differences in the age at the initiation of amblyopic treatment, BCVA improvement from initial to final visits, and treatment success rate between the add-on CAM training and the control groups. Significantly, the duration to reach BCVA ≥20/25 was shorter in the add-on CAM training group (10.08±8.24wk) than in the control group (22.67±13.24wk; *P*<0.001). The rates of final BCVA ≥20/30 (*P*=0.045) and improvement of VA ≥3 lines (*P*=0.046) were lower in the add-on CAM training group than in the control group. In moderate bilateral amblyopia, the mean age at the initiation of amblyopic treatment and the improvement of BCVA from initial to final visits, as well as the rate of final BCVA ≥20/30 and the improvement of VA ≥3 lines, did not differ between the add-on CAM training and control groups. Similar to moderate unilateral amblyopia, the duration to reach BCVA ≥20/25 was significantly shorter in the add-on CAM training group (12.21±7.40wk) than in the control group (32.31±24.41wk; *P*=0.002).

Risk Factors for Treatment Failure After Add-on CAM Training in Amblyopic Children According to the response to treatment, the amblyopic eyes were divided into two groups: treatment success (final BCVA ≥20/25) and treatment failure groups (Table 3). In unilateral amblyopic eyes, the initial logMAR BCVA was 0.41±0.19 in the treatment success group, which was significantly better than that in the treatment failure group (*P*<0.001). Moreover, the depth of amblyopia was significantly lower in the treatment success group than in the treatment failure group (*P*<0.001). The median sessions and duration of CAM training to reach BCVA ≥20/25 in the treatment success group were 6wk (range: 2–31wk) and 7wk (range: 2–40wk), respectively. In contrast, the median sessions and duration of CAM training that were needed to achieve final BCVA were 9wk (range: 4–52wk) and 19wk (range: 7–82wk), respectively, in the treatment failure group. There was no significant difference in the age at the initiation of training, sex, distribution of refraction, or the median time interval from the initiation of occlusion therapy to CAM training between the groups.

In bilateral amblyopic eyes, the initial logMAR BCVA in the treatment success group (0.38±0.22) was significantly better than that in the treatment failure group (0.78±0.29; *P*<0.001). Compared to the treatment success group, the astigmatism power was higher (*P*=0.007), and the depth of amblyopia was more severe (*P*=0.006), in the treatment failure group. The median sessions and duration of amblyopic training to attain BCVA ≥20/25 in the treatment success group were 5wk (range: 2–28wk) and 6wk (range: 2–32wk), respectively. In the treatment failure group, the median sessions and duration of CAM training needed to achieve final BCVA were 6.5wk (range: 4–45wk) and 10wk (range: 4–59wk), respectively. There was no significant difference in the age at the initiation of training or sex between the groups.

DISCUSSION

This was a pilot case-control study to demonstrate the clinical course and visual outcomes after standard amblyopic treatment add-on CAM training in children with refractive amblyopia in Taiwan. We found that 84% (105/129 cases) of amblyopic eyes had treatment success (final BCVA ≥20/25) after add-on CAM training, and the initial BCVA determined the visual outcomes in either unilateral or bilateral amblyopia. In moderate amblyopia, which presented in either unilateral or bilateral eyes, the BCVA improvement from initial to final visits and the treatment success rate were comparable between the add-on CAM training and control groups. However, the treatment duration to achieve success (BCVA ≥20/25) was significantly shorter in the add-on CAM training groups than in the control group.

Table 3 Possible factors influencing final VA after add-on CAM training in unilateral and bilateral amblyopia mean±SD

Parameters	Unilateral amblyopia			Bilateral amblyopia		
	Treatment success (*n*=50)	Treatment failure (*n*=16)	*P*	Treatment success (*n*=55)	Treatment failure (*n*=8)	*P*
Age (y)	5.28±0.95	5.44±1.46	0.690	4.98±0.87	5.25±1.91	0.706
Gender (*n*, M/F)	22/28	10/6	0.255	26/29	3/5	0.716
Fellow eyes						
Initial BCVA (logMAR)	0.08±0.10	0.08±0.13	0.921			
Final BCVA (logMAR)	0.01±0.03	0.05±0.08	0.115			
Lesion eyes						
Initial BCVA (logMAR)	0.41±0.19	0.80±0.31	<0.001	0.38±0.22	0.78±0.29	<0.001
Depth of amblyopia (Initial BCVA)			<0.001			0.006
Severe (<20/100)	1 (2.0%)	6 (37.5%)		3 (5.5%)	3 (37.5%)	
Moderate (≥20/100 and ≤20/40)	39 (78.0%)	10 (62.5%)		34 (61.8%)	5 (62.5%)	
Mild (>20/40)	10 (20.0%)	0		18 (32.7%)	0	
Final BCVA (logMAR)	0.02±0.04	0.42±0.28	<0.001	0.01±0.02	0.45±0.41	<0.001
Refractive errors (*n*)						
Hypermetropia	10 (+5.20±0.94 D)	4 (+4.44±1.01 D)	0.204	6 (+6.33±2.35 D)	0	-
Myopia	2 (-7.88±1.24 D)	0	-	1 (-6.50 D)	1 (-10.75D)	-
Astigmatism	37 (-2.95±1.30 D)	11 (-2.52±0.85 D)	0.315	44 (-2.86±1.17 D)	6 (-4.33±1.33 D)	0.007
Astigmatism only	22	6		21	2	
Hypermetropia+astigmatism	6	1		17	1	
Myopia+astigmatism	9	4		6	3	
Sessions of CAM to reach BCVA 20/25 or final VA (median)	6 (range 2–31)	9 (range 4–52)	-	5 (range 2–28)	6.5 (range 4–45)	-
Duration of CAM to reach BCVA 20/25 or final VA (wk, median)	7 (range 2–40)	19 (range 7–82)	-	6 (range 2–32)	10 (range 4–59)	-
Occlusion to training interval (mo, median)	1 (range 0–37)	1 (range 0–19)	0.325			

BCVA: Best-corrected visual acuity; CAM: Cambridge Visual Stimulator; SD: Standard deviation; VA: Visual acuity.

The treatments of unilateral amblyopia include patching, pharmacologic occlusion therapy with atropine, and optical penalization of the sound eye[24-26]. The study from the PEDIG demonstrated that among 3- to 7-year-old children with unilateral and moderate amblyopia, 63% of the children had a final VA ≥20/30, and 41% of the children had a final VA ≥20/25 after occlusion therapy at 6mo[27]. Our study results showed that 6mo after add-on CAM training, 83.7% (41/49 cases) of children with moderate unilateral amblyopia had a final BCVA ≥20/30, whereas 79.6% (39/49 cases) of the children had a final BCVA ≥20/25 (Table 2). The small sample size in the control group may be the reason why the percentages of children with a final BCVA ≥20/30 and VA improvement ≥3 lines were higher in the control group than in the add-on CAM training group. The recent study including 28 cases aged 4–12 years old in daily multimedia perception learning software program for 3mo showed no significant difference in BCVA improvement compared to the control group (2.07 *vs* 1.93 lines; *P*=0.481)[28]. Similarly, our study enrolled 49 moderate unilateral amblyopic patients aged 4–9 years old in the add-on CAM training group did not exhibit better visual improvement at 6mo or a treatment success rate than those children in the control group. However, the add-on CAM training significantly shortened the duration to reach BCVA ≥20/25 (10.08±8.24 *vs* 22.67±13.24wk, *P*<0.001). This result implies that add-on CAM training weekly seems to be more efficient than occlusion therapy alone and accelerates the improvement of VA in moderate unilateral amblyopia. In addition, our study had longer follow-up duration to 6mo and the results may be more comprehensive because some patients had BCVA improvement in the extended training sessions.

For bilateral amblyopia, Wallace *et al*[29] reported the treatment outcome of bilateral amblyopic children (mean age: 5.1y) with hypermetropia ≥+4.0 D by SE and/or astigmatism ≤-2.0 D. The mean VA improvement was 3.9 lines from baseline, and the cumulative probability of binocular VA ≥20/25 was 74% within one year. In our previous study, 90.9% (10 in 11 patients) of children with bilateral high hypermetropia (SE ≥+4.5 D) reached BCVA ≥20/25 over a mean of 6.15wk[21]. In the present study, there were 50 children with bilateral hypermetropia (SE ≥+4.0 D) or astigmatism ≤-2.0 D in the add-on CAM training group, and the mean VA improvement was 3.5 lines. Forty-four of them (88%) achieved a final BCVA ≥20/25 at a mean time of 8.6wk. Although BCVA improvement from the initial visit to the 6-month visit, the treatment success rate, and the number of children who acquired a final BCVA ≥20/30 or VA improvement ≥3 lines were similar to the control group, the add-on CAM training group experienced a significantly shorter duration to achieve BCVA ≥20/25. These results indicate that add-on CAM training is effective and shortens the treatment course in bilateral refractive amblyopia.

Treatment failure is consistently a challenge for amblyopic children. In the PEDIG study, the treatment failure rate (which was classified as the proportion of children with a final VA <20/30 or VA improved from baseline to less than 3 lines at 6mo) was 21% after occlusion therapy for unilateral and moderate amblyopic children aged 3–7y[30]. Another study showed that the treatment failure rate (which was defined as a final VA <20/32) was 48.4% in anisometropic patients aged 7–9y with a mean follow-up time of 33.6mo[31]. In this study, the overall rate of treatment failure (defined as a final BCVA <20/25) was 18.6%, and 16.3% (8/49 cases) of children with moderate unilateral amblyopia could not reach a final BCVA of 20/30 at 6mo after add-on CAM training. Compared with children with unilateral amblyopia in the control group, the add-on CAM training group had a higher treatment failure rate and a worse final BCVA, which could be explained by the worse initial BCVA and the greater number of children with severe amblyopia in the add-on CAM training group. This was comparable with observations from our clinical practice that children with younger ages and more favorable initial BCVA tended to adopt conservative treatments. A previous study demonstrated that 52% of unilateral amblyopic children who improved at least 3 lines from baseline achieved the maximum improvement by 16wk[27]. Our results also showed that for those children who failed to attain final BCVA ≥20/25 with add-on CAM training, the median number of sessions to achieve final BCVA was 6.5 to 9 times within 10–19wk of the treatment duration. We speculated that if VA did not gain favorable improvements after add-on CAM training for 3 to 4mo, other training methods should be attempted.

Several studies have reported of the risk factors for treatment failure after standard training. Stewart *et al*[16] reported that in children with unilateral amblyopia, the occlusion dose, initial VA of amblyopia, binocular vision status (such as stereopsis), fixation of the amblyopic eye, and age were the influencing factors for the visual outcome after standard treatment. Other studies found that a high SE of >+3.0 D, poor initial VA, significant astigmatism (≤-1.5 D), age above 6y, and types of refraction errors were risk factors for poor responses to treatment in anisometropic amblyopia[15,22,31-32]. In children with bilateral amblyopia, our previous study found that a worse initial VA, myopia, and ages younger than 4-year-old had poor visual improvements after CAM training[21]. Similarly, our present study showed that a worse initial BCVA, as well as the depth of amblyopia, were the main risk factors for treatment failure in both unilateral and bilateral amblyopia groups after add-on CAM training. In the bilateral amblyopia group, the children with higher cylinder power had decreased chances of obtaining treatment success. However, our present study showed that the age at the initiation of add-on CAM training did not affect the final VA, which was in contrast to the report that the visual outcomes of unilateral amblyopic children older than 7- to 13-year-old were less responsive to amblyopia treatment than children younger than 7 years of age[33]. We presumed that more than 80% of the enrolled children were under the age of 7y, which may be the reason for the difference from a previous report.

There were several limitations in this study, and one of them was its retrospective nature. Due to the fact that some of the amblyopic children could not attend the add-on CAM training program weekly for personal reasons, the sessions of CAM training were not the same as the duration for obtaining final BCVA, and some potential children were excluded. Other limitations included the small sample size after dividing the groups during the analysis, the control group lacking a matched age and initial VA, and the lack of long-term visual outcome after add-on CAM training. Nonetheless, our promising results showed that add-on CAM training is effective and efficient for both unilateral and bilateral amblyopia. Further large and randomized controlled studies will be needed to prove the sound effect of add-on CAM training and to monitor its long-term efficacy and amblyopic recurrence.

In conclusion, we found that 81.4% of patients aged 4–9y achieved BCVA ≥20/25 after add-on CAM training with a mean duration of 10–12wk, which was significantly shorter than that of the control group. Children with poor initial BCVA and high astigmatism were risk factors for treatment failure. Add-on CAM training is an efficient strategy to enhance visual improvement and to promote the achievement of optimal VA when VA improvement is limited after standard amblyopic treatment in children.

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