Article ▸ # The Effect of a Combined Visual Efficiency and Perceptual-Motor Training Programme on the Handwriting Performance of Children with Handwriting Difficulties: A Pilot Study

Mabel M.P. Leung, MSc, School of Optometry, The Hong Kong Polytechnic University, Hong Kong, China

Carly S.Y. Lam, PhD, School of Optometry, The Hong Kong Polytechnic University, Hong Kong, China

Sutie S.T. Lam, MSc, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong, China

Natalie W.Y. Pao, MSc, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong, China

Cecilia W.P. Li-Tsang, PhD, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong, China

ABSTRACT

Background: The purpose of this study was to investigate the effect of a combined visual efficiency and perceptual-motor training programme on the handwriting performance of Chinese children aged 6 to 9 years with handwriting difficulties (HWD).

Methods: Twenty-six children with HWD were assigned randomly and equally into two groups. The training programme was provided over eight consecutive weeks with one session per week. The perceptual-motor group received training only on perceptual-motor functions, including visual spatial relationship, visual sequential memory, visual constancy, visual closure, graphomotor control and grip control. The combined training group received additional training components on visual efficiency, including accommodation, ocular motility, and binocular fusion. Visual efficiency, visual perceptual skills, and Chinese handwriting performance were assessed before and after the training programme.

Results: The results showed statistically significant improvement in handwriting speed after the training in both groups. However, the combined training gave no additional benefit on improving handwriting speed (ANCOVA: $F=0.43$, $p=0.52$). In terms of visual efficiency, participants in the combined training group showed greater improvement in amplitude of accommodation measured with right eye ($F=4.34$, $p<0.05$), left eye ($F=5.77$, $p<0.05$) and both eyes ($F=11.08$, $p<0.01$).

Conclusions: Although the additional visual efficiency training did not provide further improvement in the handwriting speed of children with HWD, children showed improvement in their accommodation amplitude. As accommodative function is important for providing sustainable and clear near vision in the process of reading and word recognition for writing, the effect of the combined training on handwriting performance should be further investigated.

Keywords: accommodation, training, visual efficiency, perceptual-motor, handwriting

Introduction

The prevalence of handwriting difficulties (HWD) in children ranges from 6 to 37%.[1] Poor handwriting affects children's academic performance, educational development, and psychological well-being.[2-5] HWD can further hinder the accomplishment of higher-order language skills such as spelling and composition.[6] In addition, in the Chinese language, character copying skills are closely related to the development of Chinese literacy skills.[7] It is therefore crucial to develop effective interventions for children with HWD in the Chinese population.

Handwriting is a complex visual perceptual and motor integration process. It involves a number of skills including visual perception, cognitive functions, kinesthetic functions, gross and fine motor skills, and sustained attention.[8-10] Deficiency, if present, in any part of this integration process can severely affect handwriting performance. Cate and Richards reported a positive relationship between the efficiency of basic visual functions and visual-perceptual processing skills.[11] They suggested that visual efficiency is a prerequisite for higher order visual-perceptual processing; intervention should begin with visual efficiency to improve visual-perceptual processing skills. Optometrists are eye care professionals who can administer perceptual motor therapy in addition to visual efficiency therapy. This approach opened a new window for the collaboration of optometrists and occupational therapists to work on these areas.

Children who fail to master adequate handwriting skills through normal classroom learning are mostly referred to occupational therapists for investigation and management.[12]

Multisensory training, including training on visual-perceptual skills, visual motor integration, fine motor skills, and handwriting practices, is usually provided.[13] Although a higher prevalence of poor visual efficiency, such as accommodation and binocular anomalies, has been reported in children with HWD,[14] none of these skills are included in most of the conventional interventions. Study has demonstrated the effectiveness of multisensory training in improving handwriting speed and legibility;[15] however, the effectiveness of visual efficiency training has never been investigated.

The purpose of this study was to investigate whether adding visual efficiency components to the current perceptual-motor training would further enhance the handwriting performance of children with HWD. We hypothesized that a combined training of the visual efficiency and visual-perceptual skills would have a booster effect on children's handwriting performance compared to training on perceptual-motor skills alone.

Methods

Participants

Twenty-six children with HWD were recruited from Hong Kong mainstream primary schools by convenience sampling. All of them were studying at either primary 1 or 2 and used Chinese and Cantonese as their primary written and spoken languages. They were classified as having HWD using the Handwriting Ability Checklist (HAC), a validated parent-rated checklist that assesses handwriting legibility, speed, and physical and emotional responses.[16] Only children who scored below the 30th percentile in HAC were recruited. Children with physical impairments, learning disabilities, attention and behavioral problems, neuromuscular disabilities, and/or history of any previous intervention on handwriting were excluded from the study. Parents of all participants were fully informed, and written consent was obtained before the measurements and trainings were conducted. The initial visual profile of the participants was reported in a separate paper.[14]

Instruments and Outcome Measures

Eye Examination and Visual Efficiency Assessments

All participants received a general eye examination and visual function assessment including examination of ocular health (by slit lamp biomicroscopy and direct ophthalmoscopy), subjective refraction, accommodative function assessment (accommodative amplitude by push-up method monocularly and binocularly; accommodative facility by a lens flipper of +/- 2.00D binocularly), and binocularity assessment (heterophoria by cover test and prism neutralization, convergence by near point of convergence method, fusional reserve by step vergence method, vergence facility by facility prism of 3 prism dioptre base-in/12 prism dioptre base-out, and stereoacuity by Randot stereotest). All of the instructions and procedures for each test on accommodative function and binocularity were adopted from Scheiman and Wick.[17]

Test of Visual Perceptual Skills-revised (TVPS-R)

The Test of Visual Perceptual Skills (non-motor)-Revised (TVPS-R) developed by Gardner is a highly reliable and valid measure for evaluating non-motor visual analysis skills.[18] It consists of 7 subtests: visual discrimination, visual memory, visual spatial relationship, visual form constancy, visual sequential memory, visual figure-ground, and visual closure. In each subtest, there are 2 demonstration plates and 16 test plates. Participants were instructed to indicate the correct answer in each test plate shown in the testing booklet until the ceiling was reached.

Beery-Buktenica Developmental Test of Visual Motor Integration (Beery VMI-5)

The Beery-Buktenica Developmental Test of Visual Motor Integration (5th edition) is a standardized, norm-referenced test for assessing the integration of visual and motor skills.[19] There are 27 items in a series of geometric designs. The participants were required to copy each of them to the box below. They were not allowed to trace the figure with finger or pencil or to erase or work over the drawing. Their performance was checked against the corresponding scoring criteria and reference designs in the user manual.

Developmental Eye Movement Test (DEM)

The Developmental Eye Movement test (DEM) was designed for an indirect evaluation of eye movements.[20] It consists of 1 horizontal test and 2 vertical tests. The horizontal test is composed of 80 unevenly spaced digits arranged in 16 rows, which is designed to increase oculomotor involvement. On the other hand, each vertical test is composed of 40 evenly spaced digits arranged in 2 columns. It is designed as a visual-verbal test to evaluate skills in visual-verbal processing. The participants were asked to name aloud the digits as quickly and as accurately as possible. The time taken and the errors made were recorded. The test time was then adjusted for any addition or omission errors made in both the horizontal and vertical tests, which gave the adjusted horizontal and vertical scores. Lower scores represent shorter time and better performance. A ratio was obtained by dividing the adjusted horizontal score by the adjusted vertical score. A normative study was done on Cantonese-speaking children in Hong Kong.[21] The children were found to show more vertical errors but a faster speed than the norms of English- and Spanish-speaking children.

Computerized Handwriting Assessment Tool

Handwriting performance was assessed by a computerized handwriting assessment tool (Figure 1) which was designed to provide a digitized, objective, and quantitative assessment of the Chinese handwriting skills.[22] By using a wireless pressure-sensitive electronic pen, participants were asked to copy 20 Chinese characters, according to a template, onto an A4-sized paper affixed to a digitized tablet. The user's handwriting

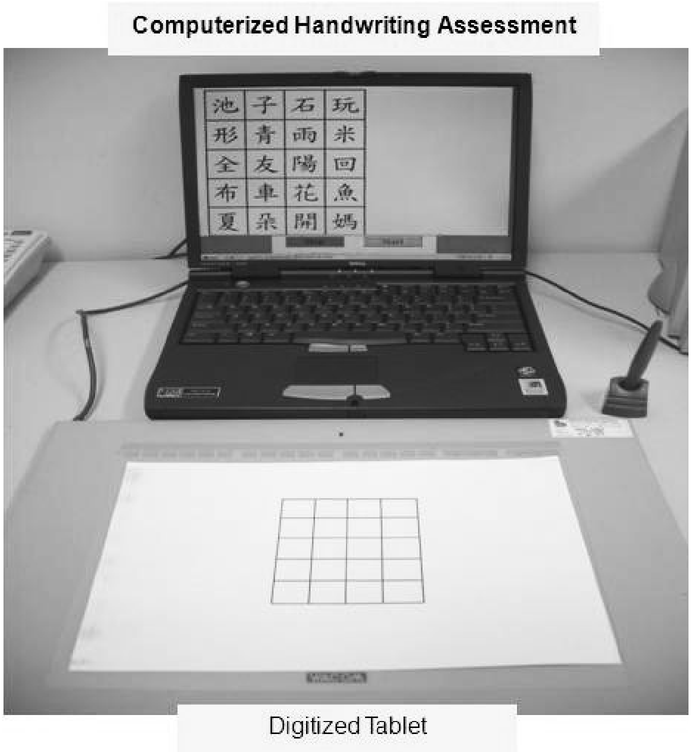

Figure 1. *The setup of the computerized handwriting assessment tool.*

product was captured, and their handwriting performance was evaluated through a computer system connected to the tablet. Participants were instructed to write quickly while keeping their handwriting legible and accurate. Handwriting speed was obtained by evaluating the recording in terms of the "On Paper" time, "In Air" time, and total time used for copying all 20 characters measured in seconds. "On Paper" time was defined as the amount of time during writing that the pen was in contact with the writing surface; "In Air" time was defined as the amount of time during writing that the pen was not in contact with the writing surface. Total time was the sum of the "On Paper" and "In Air" times. Images of the pre- and post-training handwriting samples of a subject are shown in Figure 2 and Figure 3, respectively. The blue line marked the trajectory of the pen in direct contact with the writing surface, while the green line marked the trajectory of the pen in air during the writing task.

Interventions

Training sessions were provided once per week for eight consecutive weeks. In the combined group, each session consisted of 45-minute perceptual-motor training and 30-minute visual efficiency training, while in the perceptual-motor group, each session consisted of 45-minute perceptual-motor training and 30-minute placebo visual efficiency training, resulting in a 75-minute session for both groups. Placebo therapy with similar design was proved effective in maintaining patient masking.[23]

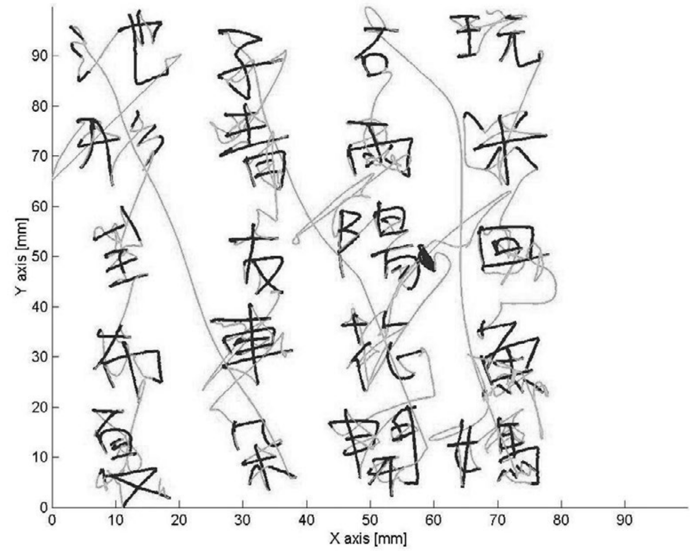

Figure 2. *The pre-training handwriting sample of a participant captured by the computerized handwriting assessment tool. The blue line marked the trajectory of the pen during direct contact with the writing surface while the green line marked the trajectory of the pen in the air during the writing task.*

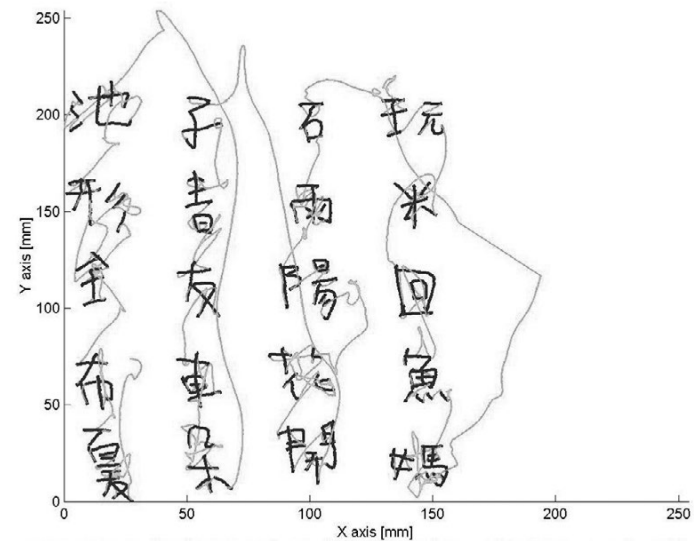

Figure 3. *The post-training handwriting sample of a participant captured by the computerized handwriting assessment tool. The blue line marked the trajectory of the pen during direct contact with the writing surface while the green line marked the trajectory of the pen in the air during the writing task.*

Perceptual-motor Training

Perceptual-motor training was performed by an occupational therapist who was not involved in the assessments. A computerized training program developed by the Department of Rehabilitation Sciences of The Hong Kong Polytechnic University was used. It was composed of a series of games that specifically focused on two themes: visual perceptual skills and visual-motor integration. Some examples are shown in Figure 4.

Training of visual perceptual skills included form perception, visual spatial relationship, visual memory, visual sequential memory, visual figure ground, visual constancy, and visual closure. Visual motor integration training consisted of eye-hand coordination and fine-motor control. A previous

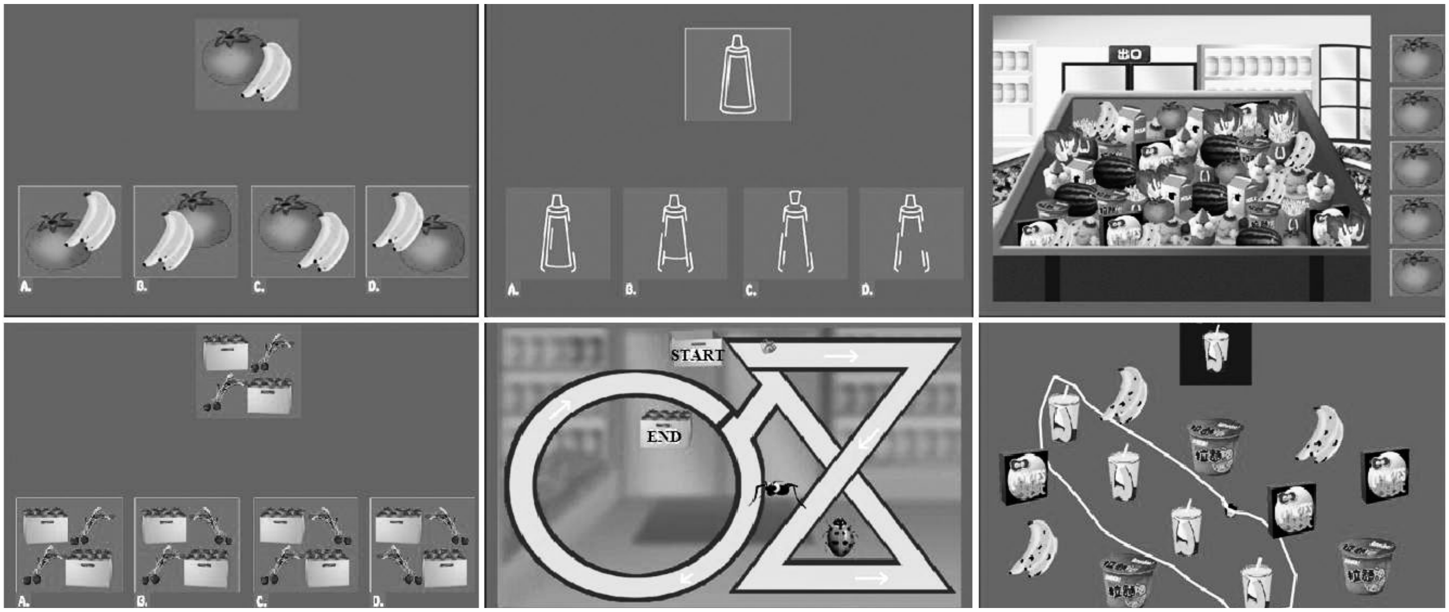

Figure 4. *The computerized perceptual-motor training activities.*

Table 1. Implementation of Visual Efficiency Training

	Visual Efficiency Training Exercises (Duration in minutes)
Session 1	HTS iNet– Saccades, monocularly at 40cm (10)* Monocular Hart Chart accommodative rock at 40cm and 3m (10)* Brock String at 40cm (10)
Session 2	HTS iNet– Saccades, monocularly at 40cm (10)* Monocular Hart Chart accommodative rock at 40cm and 3m (10)* Brock string at 1m (10)
Session 3	HTS iNet– Accommodative rock, monocularly with lens flipper +/-2.00D at 40cm (10)* Monocular Hart Chart saccades at 1m (10)* Tranaglyphs– BC520 smooth vergence base out at 40cm (10)
Session 4	HTS iNet– Saccades, binocularly at 40cm (5) HTS iNet– Accommodative rock, monocularly with lens flipper +/-2.00D at 40cm (10)* Split Hart Chart saccades, binocularly at 1 meter (5) Tranaglyphs– BC520 smooth vergence base out at 40cm (10)
Session 5	HTS iNet– Pursuits, monocularly at 40cm (10)* HTS iNet– Accommodative rock, binocularly with lens flipper +/-2.00D at 40cm (5) Tranaglyphs– BC50 series step vergence base out (5) Tranaglyphs– BC520 smooth vergence base in at 40cm (10)
Session 6	HTS iNet– Pursuits, monocularly (10)* HTS iNet– Accommodative rock, binocularly with lens flipper +/-2.00 D at 40cm (5) Aperture rule– Base out (10) Tranaglyphs– BC520 smooth vergence base in at 40cm (5)
Session 7	HTS iNet– Accommodative rock, binocularly with lens flipper +/-2.00D at 40cm (5) Pegboard rotator, monocularly (10)* Aperture rule– Base out (5) Tranaglyphs– BC50 series step vergence base in at 40cm (10)
Session 8	HTS iNet– Pursuits, binocularly at 40 cm (5) HTS iNet– Jump Ductions base in and base out at 40cm (5) Pegboard rotator, binocularly (5) BC275– Free space fusion base out at 40cm (5) Aperture rule– Base out and Base in (5)

**5 minutes for each eye = total 10 minutes*

study reported the effectiveness of visual motor integration training on improving the overall visual perceptual skills as well as handwriting speed of children.[24]

Visual Efficiency Training

The visual efficiency training sessions were provided by an optometrist not involved in the assessments. Table 1 shows the details of the implementation of each training session. Each session was 30 minutes and comprised three to five exercises. The training was targeted towards improving participants' ocular motility, amplitude and facility of accommodation, binocular fusion, peripheral awareness and eye-hand coordination. All instructions and procedures were adopted from Scheiman and Wick,[17] in which the following equipments were used: Hart Charts, lens flipper, brock string, tranaglyphs, aperture rule, opaque free space fusion card and pegboard rotator.

In addition, a computerized training program, HTS iNet (HTS, Inc., Arizona, USA) was also used as part of the in-office training. It provides a fun and easy way to promote binocular functions. The training content includes pursuits, saccades and accommodative rock, in which the computer automatically increases the difficulty based on the user's improvement. This program was found effective in improving vergence amplitudes and relieving associated symptoms.[25]

Placebo Visual Efficiency Training

In order to blind the participants on which group they belong to, placebo visual efficiency training was designed fusion, peripheral awareness, and eye-hand coordination. All instructions and procedures were adopted from Scheiman and Wick,[17] in which the following equipment was used: Hart charts, lens flippers, Brock string, tranaglyphs, aperture rule, opaque free space fusion card, and pegboard rotator.

In addition, a computerized training program, HTS iNet (HTS, Inc., Arizona, USA) was also used as part of the in-office training. It provides a fun and easy way to promote

Table 2. Visual Efficiency Functions in Both Training Groups Before and After the Training Programme

	Training Group[a]	Pre-training (Mean ± SD)	Post-training (Mean + SD)	Paired t-test[b]	ANCOVA[b]
Amplitude of Accommodation (Dioptres)					
Right Eye	CB PM	14.8 ± 1.8 14.7 ± 2.9	16.3 ± 1.5 15.0 ± 1.5	***t* = 2.37, p< 0.05** *t* = 0.55, p = 0.59	***F* = 4.34, p< 0.05**
Left Eye	CB PM	14.8 ± 1.8 14.6 ± 2.8	16.4 ±1.5 14.8 ± 1.9	***t* = 2.46, p< 0.05** *t* = 0.32, p = 0.76	***F* = 5.77, p< 0.05**
Both Eyes	CB PM	15.9 ± 1.8 15.8 ± 3.1	17.8 ± 1.5 15.8 ± 1.9	***t* = 3.15, p< 0.01** *t* = -0.06, p = 0.95	***F* = 11.08, p< 0.01**
Accommodative Facility (Cycles per minute)	CB PM	5.3 ± 3.8 5.1 ± 3.1	9.7 ± 4.5 7.5 ± 2.2	***t* = 4.39, p< 0.01** ***t* = 2.46, p< 0.05**	*F* = 1.06, p = 0.32
Stereopsis (Seconds of arc)	CB PM	30.4 ± 7.5 40.8 ± 17.5	30.0 ± 11.7 27.3 ± 8.1	*t* = -0.11, p = 0.92 ***t* = -2.88, p< 0.05**	*F* = 1.06, p = 0.32
Near Point of Convergence (centimeters)	CB PM	4.7 ± 0.7 4.9 ± 0.7	4.8 ± 1.0 5.1 ± 1.1	*t* = 0.69, p = 0.50 *t* = 0.46, p = 0.65	*F* = 0.28, p = 0.60
Heterophoria (Prism Dioptres)					
Magnitude at Distance	CB PM	0.8 ± 1.9 1.7 ± 3.3	0.5 ± 1.7 2.0 ± 2.8	*t* = -1.00, p = 0.34 *t* = 0.62, p = 0.55	*F* = 2.21, p = 0.15
Magnitude at Near	CB PM	2.6 ± 4.5 4.8 ± 5.6	3.0 ± 3.4 5.2 ± 5.6	*t* = 0.64, p = 0.54 *t* = 0.46, p = 0.65	*F* = 0.15, p = 0.71
Fusional Vergence (Prism Dioptres)					
Positive; at Distance	CB PM	19.3 ± 8.7 19.1 ± 6.8	27.0 ± 11.6 19.2 ± 8.0	*t* = 1.67, p = 0.12 *t* = 0.05, p = 0.96	*F* = 3.10, p = 0.09
Positive; at Near	CB PM	31.7 ± 8.4 35.0 ± 6.1	34.9 ± 8.1 34.6 ± 5.9	*t* = 1.17, p = 0.27 *t* = -0.14, p = 0.89	*F* = 0.00, p = 0.99
Negative; at Distance	CB PM	11.1 ± 3.5 12.1 ± 4.8	10.5 ± 2.5 11.5 ± 3.7	*t* = -0.39, p = 0.70 *t* = -0.48, p = 0.64	*F* = 0.42, p=0.53
Negative; at Near	CB PM	13.8 ± 4.7 16.5 ± 5.2	15.2 ± 4.2 16.5 ± 4.3	*t* = 0.64, p = 0.54 *t* = 0.06, p = 0.95	*F* = 0.56, p = 0.46
Vergence Facility (Cycles per minute)	CB PM	9.3 ± 5.2 11.2 ± 4.7	10.6 ± 4.2 9.6 ± 5.3	*t* = 0.86, p = 0.41 *t* = -0.99, p = 0.34	*F* = 0.97, p = 0.34

[a]*Training Groups: CB = Combined training Group; PM = Perceptual-motor Group*
[b]*Statistically significant differences shown in bold*

binocular functions. The training content includes pursuits, saccades, and accommodative rock, in which the computer automatically increases the difficulty based on the user's improvement. This program was found to be effective in improving vergence amplitudes and relieving associated symptoms.[25]

Placebo visual efficiency training

In order to blind the participants as to their group, placebo visual efficiency training was designed to look like the real visual efficiency training but without stimulating training effects. It was also carried out by an optometrist who was not involved in the assessments. Each session comprised three 10-minute activities, consistent with the visual efficiency training. The activities also looked similar to those in the visual efficiency training, where near accommodative rock charts, loose lenses, lens flippers, red/green flippers, and tranaglyphs were used.

In order to ensure that no treatment effect would be present, plano (i.e., zero-powered) loose lenses and lens flippers were used to replace lens flippers of +/-2.00D during monocular and binocular accommodative rock exercises at 40cm, respectively. By replacing red/green glasses with red/green flippers and by not separating the two slides apart during the use of tranaglyphs, no training effect would be achieved in the placebo training. Placebo therapy with similar design was proved effective in maintaining patient masking.[23]

Procedure

The study was a randomized, double-blind clinical pilot study, where both participants and assessors were blind to the training group allocation. All research procedures adhered to the tenets of the Declaration of Helsinki and were approved by the Ethics Committee of The Hong Kong Polytechnic University.

The assessments and training took place at the Optometry Clinic and the Paediatric Rehabilitation Laboratory of The Hong Kong Polytechnic University. After all baseline assessments had been conducted, participants were equally and randomly assigned to two groups, namely the combined training group and the perceptual-motor group, using sequentially-numbered, opaque, sealed envelopes. They all underwent eight sessions of 75 minutes: 45 minutes of perceptual-motor training and 30 minutes of visual efficiency or placebo training. Outcome assessments were scheduled 1 week after the completion of all training sessions. Except that ocular health assessments were excluded, all other assessments were carried out with the same procedure as were the baseline assessments.

Data Analysis

IBM SPSS 22 (SPSS Inc., Chicago, USA) was used for data analysis. As there might be maturation effect and individual differences in the development of visual and motor functions among the participants,[9,17,21] as well as baseline differences between groups, ANCOVA (with age and pre-

Table 3. Performance on TVPS-R, VMI, and DEM as Compared with Age Norm

	Training Group[a]	Pre-Training			Post-Training		
		Standard Score Mean ± SD	Subjects with Below-Average Performance[e]		Standard Score Mean ± SD	Subjects with Below-Average Performance[e]	
			Number	Percentage		Number	Percentage
TVPS-R[b]							
Visual Discrimination	CB	101.8 + 12.3	6	46.2%	96.1 + 18.4	7	53.8%
	PM	95.6 + 20.2	6	46.2%	100.3 + 13.6	5	38.5%
Visual Memory	CB	105.8 + 16.0	5	38.5%	100.6 + 17.0	6	46.2%
	PM	92.3 + 13.6	10	76.9%	99.7 + 15.9	9	69.2%
Visual Spatial Relations	CB	110.2 + 17.3	2	15.4%	105.5 + 17.3	5	38.5%
	PM	106.8 + 13.4	1	7.7%	106.0 + 17.4	2	15.4%
Visual Form Constancy	CB	99.0 + 16.7	6	46.2%	99.1 + 15.3	3	23.1%
	PM	96.2 + 10.8	8	61.5%	102.5 + 15.9	7	53.8%
Visual Sequential Memory	CB	106.5 + 13.5	4	30.8%	105.9 + 13.8	4	30.8%
	PM	95.0 + 17.3	7	53.8%	113.9 + 12.5	1	7.7%
Visual Figure Ground	CB	95.9 + 19.1	5	38.5%	102.8 + 16.2	4	30.8%
	PM	96.2 + 17.3	8	61.5%	105.1 + 9.8	5	38.5%
Visual Closure	CB	89.6 + 12.3	11	84.6%	97.4 + 19.5	7	53.8%
	PM	88.9 + 21.5	10	76.9%	104.2 + 16.9	4	30.8%
VMI[c]	CB	99.9 + 11.8	8	61.5%	98.1 + 13.0	9	69.2%
	PM	100.1 + 7.4	7	53.8%	98.5 + 7.8	6	46.2%
DEM[d]							
Vertical Time	CB		11	84.6%		11	84.6%
	PM		13	100.0%		13	100.0%
Horizontal Time	CB		13	100.0%		12	92.3%
	PM		13	100.0%		13	100.0%
Error Score	CB		8	61.5%		7	53.8%
	PM		8	61.5%		4	30.8%
Ratio	CB		12	92.3%		8	61.5%
	PM		8	61.5%		9	69.2%

[a] *Training Groups: CB = Combined training Group; PM = Perceptual-motor Group*
[b] *Test of Visual Perceptual Skills (non-motor)-Revised*
[c] *The Beery-Buktenica Developmental Test of Visual Motor Integration*
[d] *Developmental Eye Movement test*
[e] *Performance considered below average if: standard score <100 in TVPS-R and VMI or percentage rank <50% in DEM*

training measurements entered as the covariates) was used for between-group comparisons of all the post-training measurements. Paired t-test was used to compare the pre- and post-training measurements within each training group. Effect size is computed by the Cohen's d for the magnitude of the training effect: Effect size = (Mean post – Mean pre)/SD.[26]

Subjects' raw scores in TVPS-R and VMI were converted into standard scores according to the age-matched conversion tables in the user manuals. The mean standard score was 100 for children of all ages in both tests.[18,19] A subject's performance was considered below average if the standard score was below 100. A subject's performance in the DEM test was compared with the age-matched Chinese norms[21] and was considered below average if performance was under the 50th percentile.

Results

Demographic Data

Twenty-six children with HWD participated in the study, in which 69% and 62% were males in the combined training group and the perceptual-motor group, respectively. The mean age of the combined training group (n=13) was 8.0 years (range: 6.9 to 9.5 years) and the perceptual-motor group (n=13) was 8.4 years (range: 6.8 to 9.9 years). No significant age difference was found between the groups (t = -1.16, p = 0.26).

Changes in Visual-related Functions Visual Efficiency Functions

Table 2 summarizes the means, standard deviations, and within- and between-group differences (by paired t-test and ANCOVA, respectively) on the different visual efficiency functions for the combined training group and the perceptual-motor group before and after the training. Comparing with the established norms for Caucasians,[27] the pre-training accommodative facility of subjects in both groups was relatively normal. However, comparing with the performance of a group of age-matched Chinese children, performance was poor.[14]

Statistical analysis showed significant between-group differences in the amplitude of accommodation measured with right eye (F=4.34, p<0.05), left eye (F=5.77, p<0.05) and both eyes (F=11.08, p<0.01). In the combined training group, significant improvement in the amplitude of accommodation was found when measured with right eye (1.5±2.2D; t=2.37, p<0.05), left eye (1.6±2.4D; t=2.46, p<0.05) and both eyes (1.8±2.1D; t=3.15, p<0.01), respectively. On the other hand, no significant improvement was found in the amplitude of accommodation after the perceptual-motor training alone (right eye: t=0.55, p=0.59; left eye: t=0.32, p=0.76; both eyes: t=-0.06, p=0.95).There was significant improvement in the mean accommodative facility of 4.4±3.6 cycles per minute (cpm) in the combined training group (t=4.39, p<0.01) and 2.4±3.6 cpm in the perceptual-motor group (t=2.46, p<0.05) after the training. However, no significant between-group difference was found (F=2.37, p=0.14).

Except for significant within-group changes in stereopsis in the perceptual-motor group (t=2.88, p<0.05; combined training group: t=-0.11, p=0.92), there were no significant

Table 4. Visual Perceptual Skills and Handwriting Speed in Both Training Groups Before and After the Training Programme

	Training Group[a]	Pre-training (Mean ± SD)	Post-training (Mean ± SD)	Paired t-test[e]	ANCOVA[e]
TVPS-R[b]					
Total Score	CB	76.7 ± 15.5	79.8 ± 16.1	*t* = 1.22, p = 0.25	***F* = 5.93, p< 0.05**
	PM	74.9 ± 13.3	86.8 ± 11.6	***t* = 5.29, p< 0.01**	
Visual Discrimination	CB	11.9 ± 2.4	11.4 ± 3.3	*t* =-0.75, p = 0.47	*F* = 2.02, p = 0.17
	PM	11.5 ± 3.3	12.6 ± 2.1	*t* = 1.35, p = 0.20	
Visual Memory	CB	12.2 ± 2.6	11.9 ± 2.5	*t* = -0.51, p = 0.62	*F* = 3.47, p = 0.08
	PM	11.0 ± 1.9	12.4 ± 1.7	***t* = 2.21, p< 0.05**	
Visual Spatial Relations	CB	13.4 ± 3.2	13.2 ± 2.7	*t* = -0.33, p = 0.74	*F* = 0.01, p = 0.93
	PM	13.4 ± 2.1	13.3 ± 3.1	*t* = -0.09, p = 0.93	
Visual Form Constancy	CB	10.2 ± 3.1	10.5 ± 3.0	*t* = 0.46, p = 0.66	*F* = 0.38, p = 0.54
	PM	10.1 ± 1.7	11.3 ± 3.0	*t* = 1.95, p = 0.08	
Visual Sequential Memory	CB	11.1 ± 2.5	11.5 ± 2.4	*t* = 0.48, p = 0.64	*F* = 3.41, p = 0.08
	PM	9.8 ± 2.9	13.2 ± 1.6	***t* = 3.64, p< 0.01**	
Visual Figure Ground	CB	9.7 ± 3.9	11.3 ± 2.9	*t* = 1.80, p = 0.10	*F* = 0.15, p = 0.70
	PM	10.4 ± 2.9	12.1 ± 1.7	***t* = 2.38, p< 0.05**	
Visual Closure	CB	8.3 ± 2.9	10.2 ± 3.6	*t* = 1.86, p = 0.09	*F* = 1.15, p = 0.30
	PM	8.7 ± 3.6	11.8 ± 3.1	***t* = 3.51, p< 0.01**	
VMI[c]	CB	17.3 ± 2.8	17.3 ± 3.3	*t* = 0.00, p = 0.99	*F* = 0.00, p = 0.99
	PM	18.0 ± 1.8	18.1 ± 2.0	*t* = 0.12, p = 0.91	
DEM[d]					
Vertical Time	CB	61.4 ± 17.7	56.1 ± 13.9	***t* = -2.19, p< 0.05**	*F* = 0.02, p = 0.88
	PM	63.1 ± 16.6	58.2 ± 14.0	*t* = -2.14, p = 0.05	
Horizontal Time	CB	89.6 ± 32.4	80.2 ± 32.1	*t* = -1.69, p = 0.12	*F* = 0.20, p = 0.66
	PM	83.5 ± 34.9	71.9 ± 17.3	*t* = -1.67, p = 0.12	
Error Score	CB	6.4 ± 6.2	4.4 ± 5.3	*t* = -1.65, p = 0.12	*F* = 2.01, p = 0.17
	PM	6.2 ± 4.9	5.3 ± 6.7	*t* = -0.44, p = 0.67	
Ratio	CB	1.4 ± 0.2	1.4 ± 0.3	*t* = -0.49, p = 0.64	*F* = 0.25, p = 0.63
	PM	1.3 ± 0.3	1.3 ± 0.1	*t* = -0.71, p = 0.49	
Handwriting Speed	CB	123.5 ± 42.8	110.2 ± 40.5	***t* = -3.04, p< 0.05**	F = 0.43, p = 0.52
	PM	148.1 ± 55.4	119.1 ± 52.8	***t* = -2.69, p< 0.05**	

[a]Training Groups: CB = Combined training Group; PM = Perceptual-motor Group
[b]Test of Visual Perceptual Skills (non-motor)-Revised
[c]The Beery-Buktenica Developmental Test of Visual Motor Integration
[d]Developmental Eye Movement test
[e]Statistically significant differences shown in bold

differences in the measurements of near point of convergence (F=0.28, p=0.60), heterophoria (distance: F=2.21, p=0.15; near: F=0.15, p=0.71), fusional vergence (F=0.00 to 3.10; p=0.09 to 0.99), and vergence facility (F=0.97, p=0.34) before and after the training for both groups.

Visual Perceptual Skills

Table 3 shows the subjects' performance including the mean standard score on the TVPS-R compared with the age norm. Before training, 20 subjects showed below-average performance in 3 or more TVPS-R subtests, with 11 showing below-average performance in 4 or more subtests. Among those who showed below-average performance in 4 or more subtests, 8 were from the perceptual-motor group and 3 were from the combined group. After training, the total number of subjects who showed below-average performance in 3 or more subtests reduced to 14, while below-average performance in 4 or more subtests reduced to 4.

There was a significant between-group difference in the total score of the TVPS-R after the training (F=5.93, p<0.05); the perceptual-motor group showed significant improvement (t=5.29, p<0.01), while no significant change was found in the combined training group (t=1.22, p=0.25). Children in the perceptual-motor group showed significant improvement in the subtest scores of Visual Memory (t=2.21, p<0.05), Visual Sequential Memory (t=3.64, p<0.01), Visual Figure Ground (t=2.38, p<0.05) and Visual Closure (t=3.51, p<0.01). Surprisingly, there was no significant improvement in the individual subtest scores in the combined training group.

Visual-Motor Integration

More than half of the subjects showed below-average performance in VMI before training (Table 3). The t-tests showed no significant difference in the VMI scores before and after the training in both groups. The ANCOVA results also reported no significant difference in the post-training scores between the two groups (F=0.00, p=0.99).

Developmental Eye Movement Test

Before training, over 80% of the subjects showed below-average performance on the DEM test, especially in the vertical and horizontal time (Table 3). After the training, within-group pre- and post-training comparisons showed significant improvement in the DEM adjusted vertical score (t=-2.19, p<0.05) in the combined training group and a marginally significant improvement in the perceptual-motor group (t=-2.14, p=0.05); no significant between-group difference was found (F=0.02, p=0.88). There were no significant within- and between-group differences for other DEM scores.

Changes in Handwriting Performance

After the training, the mean handwriting speed improved significantly in the combined training group (t=-3.04, p<0.05; effect size d=0.3192) and in the perceptual-motor group (t=-2.69, p<0.05; d=0.5358). The mean total writing time decreased from 123.5 seconds (SD = 42.8 seconds) pre-training to 110.2 seconds (SD = 40.5 seconds) post-training in the combined training group; that of the perceptual-motor group also decreased from 148.1 seconds (SD = 55.4 seconds) to 119.1 seconds (SD = 52.8 seconds). However, there was no significant difference between the groups at the post-training measurement (F=0.43, p=0.52).

Comparing the within-group pre- and post-training "On Paper" and "In Air" times, significant improvements were found for "On Paper" time in the perceptual-motor group (t=-3.10, p<0.01) and marginally for "In Air" time in the combined training group (t=-2.17, p=0.05). However, there was no statistically significant difference between groups.

Table 4 summarizes the means, standard deviations, and within- and between-group differences of the TVPS-R, VMI, DEM, and handwriting speed measurements for the combined training and perceptual-motor groups before and after the training.

Discussion

Effects of Perceptual-Motor Training

Our subjects showed problems in perceptual-motor skills as reflected by their below-average performance on the TVPS-R and VMI before training. Our perceptual-motor training produced improvement in visual-perceptual skills as well as accommodative facility. In line with previous studies,[24,28] no training effect was found in visual motor integration with this perceptual-motor training. Although children with HWD have been reported to have associated weaknesses in visual-motor integration,[14] the problem is more related to motor difficulty,[28,29] which was not evaluated in this study. Poon et al. argue that a long-term intensive motor training is required to promote visual motor integration, while the training in the present study was relatively short and thus might not be able to produce the desired effect.[24]

Consistent with previous study,[15] perceptual-motor training had its own effect in improving handwriting speed. It has been suggested that children with HWD co-exhibit some visual perceptual problems.[14] Assuming a causal relationship between perceptual-motor components and handwriting performance in children with HWD, intensive training on these components would produce a significant improvement on handwriting.[15]

Effects of the Additional Visual Efficiency Training

After the training, the mean handwriting speed improved significantly in the combined training group (t=-3.04, p<0.05; effect size d=0.3192) and in the perceptual-motor group (t=-2.69, p<0.05; d=0.5358). The training effect seems to be stronger in the perceptual-motor group than the combined training group based on the effect size. Apart from the relatively poor accommodative facility, our subjects had fairly normal visual efficiency skills, and therefore, the impact of visual efficiency training might be minimal. In addition, children in the combined training group did not produce significant improvement in visual perceptual skills as those in the perceptual-motor group. It appears that the improvement observed in the perceptual-motor group was masked by the additional visual efficiency training. Besides, there was improvement in handwriting speed comparing the pre- and post-training measurements in the combined training group due to reduced in-air time. This means that the improved visual efficiency resulted in shorter time required to look at and recognize the characters.[30] However, there was no additional benefit of visual efficiency training on overall handwriting speed between two groups.

In contrast, compared to the perceptual-motor group, children who received additional visual efficiency training showed greater improvement in amplitude of accommodation. Since previous studies noted a higher prevalence of accommodative anomalies in children with HWD,[14,31] our finding is a significant one toward the training approach for children with HWD. Improved accommodative function can help children to have better attention, resulting in better oculomotor control.[32,33] This in turn leads to faster visual processing.[34]

Accommodative function is important for sustainable and clear near vision.[35] Symptoms of accommodative insufficiency include impaired reading performance, light sensitivity, blurry vision, diplopia, asthenopia, headaches, and difficulties with attention and concentration, which manifest after prolonged near tasks. Chase et al. found that individuals with accommodation problems started to report symptoms after reading for more than 15 minutes.[35] The handwriting task in the present study required less than three minutes to complete, which was too short to reflect the actual benefits of the improved accommodative function. In addition, Weisz showed that training on accommodation is effective for improving children's accuracy on a pencil-and-paper task but not on improving the speed.[36] However, in the present study, data regarding handwriting legibility was not available for comparison.

The present data provides us an insight for the design of intervention. The findings in visual-perceptual skills in the combined training group illustrate the importance of balancing the components between visual efficiency and visual perceptual skills. The combined training might have provided too much information in both visual efficiency and visual perceptual domains. It overloaded the cortical system to allocate resources for permanent changes, so that children might have difficulty grasping two skills at the same time. Due to the complex relationship between visual efficiency, oculomotor control, and visual perceptual skills which affects reading and writing development,[37] the all-around changes in visual function have the impact of improving students' automaticity in handwriting.[38] As a result, combined training is still recommended, with a bottom-up approach to introduce visual efficiency followed by visual perceptual skills.

In addition, the training period in this study may have been too short to cause significant changes in both visual efficiency and visual perceptual skills, or may even have masked the changes in visual-perceptual skills, even though improvement was shown in handwriting speed. In order to have better integration between these two skills, a combined training with longer duration is recommended for the interaction and modulation between visual efficiency and visual perceptual skills so that the changes and continuous outcome on the global development of visual functions could be illustrated.

Limitations and Suggestions for Further Studies

The handwriting assessment in the present study only involved a short writing task which assessed handwriting speed. As children with HWD have a higher prevalence of accommodative anomalies that usually manifest after prolonged near tasks,[14] it would be ideal to have monitored the variation in writing performance during the writing task. Besides, training on accommodation was found to improve accuracy on a pencil-and-paper task.[36] The relationship between visual-perceptual skills and handwriting legibility has been reported.[39] Hence, this would be better quantified if we had included evaluation on handwriting legibility and sustainability.

Unlike in phonological alphabetic languages such as English and Dutch, the complex orthographical structures of Chinese characters may pose greater visual demands. Most studies concerning the relationship between visual functions, neural processing, and handwriting performance are based on alphabetic languages. Since Chinese children with HWD rely more on visually-directed processes for handwriting,[40] a study on a larger scale would allow better understanding of the roles of visual function on Chinese handwriting performance.

To be consistent with the conventional perceptual-motor training, the visual efficiency training was designed with one session per week. In general, conventional binocular vision, eye movement, and accommodative training are recommended with higher training frequency.[17] The lowered training frequency in this study might have altered the effectiveness of the training. Therefore, further studies with modification of the training protocol such as duration, frequency, and organization of training content should be considered. For example, home programs could be provided for a short period of time five days per week.

Conclusion

Additional visual efficiency components on top of existing perceptual-motor training did not provide a booster effect on improving handwriting speed. Interestingly, it probably masked the effects of perceptual-motor training on improving visual perceptual skills that were shown in the previous studies. However, the additional visual efficiency training significantly improved children's accommodative amplitude, which is important for sustainable and clear near vision for reading. Further studies on the relationship between visual efficiency, visual perceptual skills, and handwriting performance are recommended. These would provide a clearer picture on how the two levels of visual function interact in handwriting performance. They also would facilitate the collaboration of occupational therapists and optometrists in designing training that result in a combined effect.

Acknowledgements

We would like to thank Dr. Sam C.K. Cheng, Ms. Fion O.Y. Wong, Ms. Daisy K.Y. Leung, and Ms. Linda F.L. Tse for their contribution to this project. We would also like to thank Dr. Ricky KC Au for statistical advice. This study was supported by grants from the PolyU Central Research Grant (Account no. G-YF14 G-YF92). There were no conflicts of interest in publishing the results.

References

1. Overvelde A, Hulstijn W. Handwriting development in grade 2 and grade 3 primary school children with normal, at risk, or dysgraphic characteristics. Res Devel Disabil 2011;32:540-8.
2. Hammerschmidt SL, Sudsawad P. Teachers' survey on problems with handwriting: referral, evaluation, and outcomes. Am J Occupat Ther 2004;58:185-92.
3. Markham LR. Influences of handwriting quality on teacher evaluation of written work. Am Ed Res J 1976;13:277-83.
4. Roussounis SH, Gaussen TH, Stratton P. A 2-year follow-up study of children with motor coordination problems identified at school entry age. Child: Care, Health Devel 1987;13:377-91.
5. Simner ML. Printing errors in kindergarten and the prediction of academic performance. J Learning Disabil 1982;15:155-9.
6. Pontart V, Bidet-Ildei C, Lambert E, Morisset P, et al. Influence of handwriting skills during spelling in primary and lower secondary grades. Frontiers in Psychol 2013;4:818.
7. McBride-Chang C, Chung KK, Tong X. Copying skills in relation to word reading and writing in Chinese children with and without dyslexia. J Exp Child Psychol 2011;110:422-33.
8. Bonney M-A. Understanding and assessing handwriting difficulty: Perspectives from the literature. Australian Occupat Ther J 1992;39:7-15.
9. Feder KP, Majnemer A. Handwriting development, competency, and intervention. Devel Med Child Neurol 2007;49:312-7.
10. Rosenblum S, Weiss P, Parush S. Product and process evaluation of handwriting difficulties. Ed Psychol Rev 2003;15:41-81.
11. Cate Y, Richards L. Relationship between performance on tests of basic visual functions and visual-perceptual processing in persons after brain injury. Am J Occupat Ther 2000;54:326-34.
12. Reisman JE. Poor handwriting: who is referred? Am J Occupat Ther 1991;45:849-52.
13. Woodward S, Swinth Y. Multisensory approach to handwriting remediation: perceptions of school-based occupational therapists. Am J Occupat Ther 2002 May-Jun;56(3):305-12.
14. Leung MM, Lam CS, Lam SS, Pao NW, Li-Tsang CW. Visual profile of children with handwriting difficulties in Hong Kong Chinese. Res Devel Disabil 2014;35:144-52.
15. Denton PL, Cope S, Moser C. The effects of sensorimotor-based intervention versus therapeutic practice on improving handwriting performance in 6- to 11-year-old children. Am J Occupat Ther 2006;60:16-27.
16. Tam TH. A validation study on Handwriting Ability Checklist (HAC). Hong Kong: The Hong Kong Polytechnic University, 2008.
17. Scheiman M, Wick B. Clinical Management of Binocular Vision: Heterophoric, accommodative and Eye Movement Disorders. 3rd ed. Philadelphia: Lippincott Williams & Wilkins, 2008.

18. Gardner MF. Test of Visual-Perceptual Skills (Non-Motor)-Revised. US: Academic Therapy Publications, 1996.

19. Beery KE, Buktenica NA, Beery NA. The Beery-Buktenica Developmental Test of Visual-Motor Integration. 5th Ed. US: NCS Pearson, 2004.

20. Richman JE, Garzia RP. Developmental eye movement test (DEM), version 1, examiner's booklet. Mishawaka: Bernell Corporation, 1987.

21. Pang PC, Lam CS, Woo GC. The developmental eye movement (DEM) test and Cantonese-speaking children in Hong Kong SAR, China. Clin Exp Optom 2010;93:213-23.

22. Chang SH, Yu NY. Computerized Handwriting Analysis in Children with/without Motor Incoordination. In: Lim C, Goh JH, eds. 13th International Conference on Biomedical Engineering. Heidelberg; Springer Berlin. 2009:402-5.

23. Kulp M, Mitchell GL, Borsting E, Scheiman M, et al. Effectiveness of placebo therapy for maintaining masking in a clinical trial of vergence/accommodative therapy. Invest Ophthalmol Vis Sci 2009;50:2560-6.

24. Poon KW, Li-Tsang CW, Weiss TP, Rosenblum S. The effect of a computerized visual perception and visual-motor integration training program on improving Chinese handwriting of children with handwriting difficulties. Res Devel Disabil 2010;31:1552-60.

25. Cooper J, Feldman J. Reduction of symptoms in binocular anomalies using computerized home therapy-HTS. Optometry 2009;80:481-6.

26. Cohen J. Statistical Power Analysis for the Behavioral Sciences. 2nd ed. New Jersey: Lawrence Erlbaum, 1988.

27. Scheiman M, Herzberg H, Frantz K, Margolies M. Normative study of accommodative facility in elementary schoolchildren. Am J Optom Physiol optics 1988;65:127-34.

28. Howe TH, Roston KL, Sheu CF, Hinojosa J. Assessing handwriting intervention effectiveness in elementary school students: A two-group controlled study. Am J Occupat Ther 2013;67:19-26.

29. Bonifacci P. Children with low motor ability have lower visual-motor integration ability but unaffected perceptual skills. Human Movement Sci 2004;23:157-68.

30. Li-Tsang CW, Wong AS, Leung HW, Cheng JS, et al. Validation of the Chinese Handwriting Analysis System (CHAS) for primary school students in Hong Kong. Res Devel Disabil 2013;34:2872-83.

31. Dusek W, Pierscionek B, McClelland J. A survey of visual function in an Austrian population of school-age children with reading and writing difficulties. BMC ophthalmology 2010;10(1):16.

32. Jimenez R, Gonzalez MD, Perez MA, Garcia JA. Evolution of accommodative function and development of ocular movements in children. Ophthal physiol Optics 2003;23:97-107.

33. Siderov J. Improving interactive facility with vision training. Clin Exper Optom 1990;73:128-31.

34. Ram-Tsur R, Faust M, Caspi A, Gordon CR, Zivotofsky AZ. Evidence for ocular motor deficits in developmental dyslexia: Application of the double-step paradigm. Invest Ophthalmol Vis Sci 2006;47:4401-9.

35. Chase C, Tosha C, Borsting E, Ridder WH. Visual discomfort and objective measures of static accommodation. Optom Vis Sci 2009;86:883-9.

36. Weisz CL. Clinical therapy for accommodative responses: transfer effects upon performance. J Am Optom Assoc 1979;50:209-16.

37. Engbert R. Microsaccades: A microcosm for research on oculomotor control, attention, and visual perception. Prog Brain Res 2006;154:177-92.

38. Jones D, Christensen CA. Relationship between automaticity in handwriting and students' ability to generate written text. J Ed Psychol 1999;91:44-9.

39. Tseng MH, Murray EA. Differences in perceptual-motor measures in children with good and poor handwriting. OTJR 1994;14:19-36.

40. Tseng MH, Chow SM. Perceptual-motor function of school-age children with slow handwriting speed. Am J Occupat Ther 2000;54:83-8.

Correspondence regarding this article should be emailed to Mabel M.P. Leung, MSc, at mabel.leung@polyu.edu.hk.

Leung MMP, Lam CSY, Lam SST, Pao NWY, Li-Tsang CWP. The effect of a combined visual efficiency and perceptual-motor training programme on the handwriting performance of children with handwriting difficulties: a pilot study. Optom Vis Perf 2015;3(1):62-71.

The online version of this article contains digital enhancements.