The effect of a combined visual efficiency and perceptual-motor training programme on the handwriting performance of children with handwriting difficulties

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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 HWD.

Methods: Twenty-six children with HWD were assigned randomly and equally into two groups. The training programme was provided in 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. On top of this, the combined training group received additional training components on visual efficiency, including accommodation, ocular motility and binocular fusion. Their visual efficiency, visual perceptual skills, as well as 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 accommodation 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: training, visual efficiency, perceptual-motor, handwriting

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1. Introduction

The prevalence of handwriting difficulties (HWD) in children ranges from 6 to 37%.(1) Poor handwriting affects children's academic performance, educational development as well as 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, as well as 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 pre-requisite for higher order visual-perceptual processing, so the intervention should begin with visual efficiency to visual-perceptual processing skills. This approach opened a new window for the collaboration of optometrists and occupational therapists to work on these areas.

Nowadays, children who fail to master adequate handwriting skills through normal classroom learning are mostly referred to occupational therapists for investigation and management.(12) Multisensory trainings, including training on visual-perceptual skills, visual motor integration, fine motor skills and handwriting practices, are usually provided.(13, 14) Although a higher prevalence of poor visual efficiency, such as accommodation and binocular anomalies, has been reported in children with HWD,(15) none of these skills are included in most of the conventional interventions. Numerous studies have demonstrated the effectiveness of multisensory training in improving handwriting speed and legibility,(16-19) however the effectiveness of visual efficiency training has never been investigated.

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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 on 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.

2. Method

2.1. 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, physical and emotional responses.(20) 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.

2.2. Instruments and outcome measures

2.2.1. Eye examination and visual efficiency assessments

All participants received a general eye examination and visual functions assessment included examination of ocular health (by slit lamp biomicroscopy and direct ophthalmoscopy), subjective refraction, accommodative functions 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

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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 the instructions and procedures for each test on accommodative functions and binocularity were adopted from Scheiman and Wick).(21)

2.2.2. 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.(22) 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.

2.2.3. 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 in assessing the integration of visual and motor skills.(23) 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.

2.2.4. Developmental Eye Movement Test (DEM)

The developmental eye movement test (DEM) was designed for an indirect evaluation of eye movements.(24) It consists of 1 horizontal test and 2 vertical tests. The horizontal test composed of 80 unevenly spaced digits arranged in 16 rows, which was designed to increase oculomotor

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involvement. On the other hand, each vertical test composed of 40 evenly spaced digits arranged in 2 columns. It was 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 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 represents 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.(25) The children were found to show more vertical errors but a faster speed than the norms of English- and Spanish-speaking children.

2.2.5. 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 on the Chinese handwriting skills.(26) 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 on a digitized tablet. The user's handwriting 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 recording evaluated in terms of the "On Paper" time, "In Air" time and total time used for copying all 20 characters in unit of seconds. "On Paper" time is defined as the amount of time during writing that the pen is in contact with the writing surface; "In Air" time is defined as the amount of time during writing that the pen is not in contact with the writing surface. Total time is the sum of the "On Paper" and "In Air" time. Images of the pre- and post-training handwriting samples of a subject were shown in Figure 2 and Figure 3 respectively. The Blue line marked the trajectory of

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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.

[Insert Figure 1 here]

[Insert Figure 2 here]

[Insert Figure 3 here]

2.3. Interventions

Training sessions were provided once per week for eight consecutive weeks. Each session consisted of 45-minute perceptual-motor training and 30-minute visual efficiency or placebo training, depending on the group assignment (the combined training group or the perceptual-motor group respectively), resulting in a 75-minute session for both groups.

2.3.1. Perceptual-motor training

Perceptual-motor training was run by an occupational therapist who did not involve in the assessments. A computerized training program developed by the Department of Rehabilitation Sciences of The Hong Kong Polytechnic University was used. It composed of a series of games that specifically focused on two themes: visual perception skills and visual-motor integration.

Training on visual perception skills included form perception, visual spatial relationship, visual memory, visual sequential memory, visual figure ground, visual constancy and visual closure; whilst visual motor integration training composed of eye-hand coordination and fine-motor control. A previous study has reported its effectiveness on improving the overall visual perceptual skills as well as handwriting speed of children.(13)

2.3.2. Visual efficiency training

The visual efficiency training sessions were provided by an optometrist who did not involve in the assessments. Table 1 shows the details of the implementation of each training session. Each session was 30 minutes and comprised of three to five exercises. The training was targeted on 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,(21) in which the following equipments were used: Hart Charts, lens flipper, brock string, tranaglyphs, aperture rule, opaque free space fusion card and pegboard rotator.

[Insert Table 1 here]

In addition, a computerized home training program, HTS iNet (HTS, Inc., Arizona, USA) was also adopted. 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.(27)

2.3.3. Placebo training

In order to blind the participants on which group they belong to, placebo training with content

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and procedures similar to the visual efficiency training was provided. It was also carried out by an optometrist who did not involve in the assessments. Each session was comprised of three 10-minute activities, comparative to the visual efficiency training in which three to five activities were scheduled in each session. The activities were also similar to those in the visual efficiency training where near accommodative rock charts, loose lens, lens flipper, red/green flipper and tranaglyphs were used.

In order to ensure no treatment effect would be present, plano (i.e., zero-powered) loose lens and lens flipper were used to replace lens flipper of +/- 2.00D during monocular and binocular accommodative rock exercise at 40 centimeters respectively. Besides, by replacing red/green glasses with red/green flipper and by not separating the two slides apart during the use of tranaglyphs, no training effect would be achieved in the placebo training.

2.4. Procedure

The study was a randomized, double-blind clinical pilot study, where both participants and assessors were blinded to the training group allocation. All research procedures were 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 trainings 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 45-minutes perceptual-motor training, and 30-minute visual efficiency or placebo training. Outcome assessments were scheduled 1 week after the completion of all training sessions. Except ocular health assessments were excluded, all other assessments were carried out with the same procedure as the baseline assessments.

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2.5. 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, 21, 25, 28) as well as baseline difference between groups, ANCOVA (with age and pre-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.

3. Results

3.1. 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 ($t = -1.16$, $p = 0.26$).

3.2. Changes in visual-related functions

3.2.1. 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.

[Insert Table 2 here]

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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 (by 1.5±2.2Dioptres;$t = 2.37$, $p < 0.05$), left eye (by 1.6±2.4 Dioptres; $t = 2.46$, $p < 0.05$) and both eyes(by 1.8±2.1Dioptres; $t = 3.15$, $p < 0.01$) 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: $t = -0.06$, $p = 0.95$).Furthermore, there was significant improvement in the mean accommodation 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 trainings. But no significant between-group difference was found ($F = 2.37$, $p = 0.14$).

However, except the 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 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 trainings for both groups.

3.2.2. Visual perceptual skills

There was a significant between-group difference in the total score of 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 ($t = 1.22$, $p = 0.25$). Consistent with the previous results in Poon et al.,(13) 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 ($t=3.51$, $p<0.01$).

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Surprisingly, there was no significant improvement in the individual subtest scores in the combined training group.

3.2.3. Visual-motor integration

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 score between the two groups ($F = 0.00$, $p = 0.99$).

3.2.4. Developmental eye movement

After the training, within group pre- and post-training comparisons showed significant improvement in 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 in other DEM scores.

3.3. Changes of handwriting performance

After the training, the mean handwriting speed improved significantly in the combined training group ($t = -3.04$, $p < 0.05$) and in the perceptual-motor group ($t = -2.69$, $p < 0.05$). The mean total writing time decreased from 123.5 seconds (SD = 42.8 seconds) at pre-training to 110.2 seconds (SD = 40.5 seconds) at post-training in the combined training group, while 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" time, significant improvements were found in "On Paper" time in the perceptual-motor group ($t=-3.10$, $p<0.01$) and marginally in "In Air" time in the combined training group (t=-2.17, p=0.05). However, there was no statistically significant difference between groups.

Table 3 summarized 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.

[Insert Table 3 here]

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4. Discussion

4.1. Effects of perceptual-motor training

Our perceptual-motor training produced improvement in visual-perceptual skills as well as accommodative facility. In line with previous studies,(13, 29) no training effect was found in visual motor integration with this perceptual-motor training. Although children with HWD have been reported to be associated with weaknesses in visual-motor integration,(15) the problem is more related to motor problems,(29, 30) which was not evaluated in this study. Besides, Poon et al. (2010) argued 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.(13)

Consistent with previous studies,(16, 17, 19) 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.(15) 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.(17)

4.2. Effects of the additional visual efficiency training

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 which was come from reduced in-air time. This meant that the improved visual efficiency resulted in shorter time required to look at and recognize the characters.(31) However, there was also no additional benefit of visual efficiency training on overall handwriting speed between two groups.

In contrast, comparing with the perceptual-motor group, children who received additional visual efficiency training showed greater improvement in the amplitude of accommodation. Since previous studies noted a higher prevalence of accommodation anomalies in children with HWD,(15, 32) our finding is a significant one toward the training approach for children with HWD. Improved accommodative functions can help children to have better attention, resulting in better oculomotor control (33, 34) which in turn leads to faster visual processing.(35)

Accommodation function is important for sustainable and clear near vision.(36-38) 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 task. Chase et al. found that individuals with accommodation problems started to report symptoms after reading for more than 15 minutes.(36) 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 accommodation function. In addition, Weisz showed that training on accommodation is effective on improving children's accuracy in a pencil-and-paper task, but not on improving the speed.(39) However, in the present study, data regarding handwriting legibility was

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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 illustrated 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 to grasp 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,(40) the all-round changes in visual functions have the impact of improving students automaticity in handwriting.(41) As the result, a 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 might be too short to cause significant changes in both visual efficiency and visual perceptual skills, or even 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.

4.3. 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 has a higher prevalence of accommodation anomalies that usually manifest after prolonged near task, 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 in a pencil-and-paper task.(39) A number of studies also reported the relationship between visual-perceptual skills and handwriting legibility.(42-44) Hence, this would be better quantified if we have included evaluation on handwriting legibility and sustainability.

Unlike the 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 relied more on visually-directed process for handwriting,(45) a study of a large scale would allow better understanding on the roles of visual functions 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 accommodation training are recommended with higher training frequency.(21) The lowered training frequency in this study might have affected the effectiveness of the training. Therefore, further studies with modification on 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 for five days per week.

5. Conclusion

Additional visual efficiency components on top of existing perceptual-motor training did not give a booster effect on improving handwriting speed on one hand, on the other hand, 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 accommodation amplitude that 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 firstly recommended. It would provide a clear picture on how the two levels of visual functions interact on handwriting performance. It also would facilitate the collaboration of occupational therapists and optometrists in designing trainings that result in a combined effect.

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Table 1. The implementation of visual efficiency training

	Visual Efficiency Training Exercises (30 minutes per session)
Session 1	HTS iNet– Saccades, monocularly at 40cm
	Monocular Hart Chart accommodative rock at 40cm and 3m
	Brock String at 40cm
Session 2	HTS iNet– Saccades, monocularly at 40cm
	Monocular Hart Chart accommodative rock at 40cm and 3m
	Brock string at 1m
Session 3	HTS iNet– Accommodative rock, monocularly with lens flipper +/-2.00D at 40cm
	Monocular Hart Chart saccades at 1m
	Tranaglyphs - BC520 smooth vergence base out at 40cm
Session 4	HTS iNet– Saccades, binocularly at 40cm
	HTS iNet– Accommodative rock, monocularly with lens flipper +/-2.00D at 40cm
	Split Hart Chart saccades, binocularly at 1 meter
	Tranaglyphs - BC520 smooth vergence base out at 40cm
Session 5	HTS iNet– Pursuits, monocularly at 40cm
	HTS iNet– Accommodative Rock, binocularly with lens flipper +/-2.00D at 40cm
	Tranaglyphs - BC50 series step vergence base out
	Tranaglyphs - BC520 smooth vergence base in at 40cm
Session 6	HTS iNet– Pursuits, monocularly
	HTS iNet– Accommodative rock, binocularly with lens flipper +/-2.00 D at 40cm
	Aperture rule – Base out
	Tranaglyphs - BC520 smooth vergence base in at 40cm
Session 7	HTS iNet– Accommodative rock, binocularly with lens flipper +/-2.00D at 40cm
	Pegboard rotator, monocularly
	Aperture rule – Base out
	Tranaglyphs - BC50 series step vergence base in at 40cm
Session 8	HTS iNet– Pursuits, binocularly at 40 cm
	HTS iNet– Jump Ductions base in and base out at 40cm
	Pegboard rotator, binocularly
	BC275 - Free space fusion base Out at 40cm
	Aperture rule – Base out and Base in

Table 2. The visual efficiency functions in the combined training group and perceptual-motor group 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					
Right Eye	CB	14.8 ± 1.8	16.3 ± 1.5	**$t = 2.37, p < 0.05$**	**$F = 4.34, p < 0.05$**
	PM	14.7 ± 2.9	15.0 ± 1.5	$t = 0.55, p = 0.59$	
Left Eye	CB	14.8 ± 1.8	16.4 ±1.5	**$t = 2.46, p < 0.05$**	**$F = 5.77, p < 0.05$**
	PM	14.6 ± 2.8	14.8 ± 1.9	$t = 0.32, p = 0.76$	
Both Eyes	CB	15.9 ± 1.8	17.8 ± 1.5	**$t = 3.15, p < 0.01$**	**$F = 11.08, p < 0.01$**
	PM	15.8 ± 3.1	15.8 ± 1.9	$t = -0.06, p = 0.95$	
Accommodative Facility	CB	5.3 ± 3.8	9.7 ± 4.5	**$t = 4.39, p < 0.01$**	$F = 2.37, p = 0.14$
	PM	5.1 ± 3.1	7.5 ± 2.2	**$t = 2.46, p < 0.05$**	
Stereopsis	CB	30.4 ± 7.5	30.0 ± 11.7	$t = -0.11, p = 0.92$	$F = 1.06, p = 0.32$
	PM	40.8 ± 17.5	27.3 ± 8.1	**$t = -2.88, p < 0.05$**	
Near Point of Convergence	CB	4.7 ± 0.7	4.8 ± 1.0	$t = 0.69, p = 0.50$	$F = 0.28, p = 0.60$
	PM	4.9 ± 0.7	5.1 ± 1.1	$t = 0.46, p = 0.65$	
Heterophoria					
Magnitude at Distance	CB	0.8 ± 1.9	0.5 ± 1.7	$t = -1.00, p = 0.34$	$F = 2.21, p = 0.15$
	PM	1.7 ± 3.3	2.0 ± 2.8	$t = 0.62, p = 0.55$	
Magnitude at Near	CB	2.6 ± 4.5	3.0 ± 3.4	$t = 0.64, p = 0.54$	$F = 0.15, p = 0.71$
	PM	4.8 ± 5.6	5.2 ± 5.6	$t = 0.46, p = 0.65$	
Fusional Vergence					
Positive; at Distance	CB	19.3 ± 8.7	27.0 ± 11.6	$t = 1.67, p = 0.12$	$F = 3.10, p = 0.09$
	PM	19.1 ± 6.8	19.2 ± 8.0	$t = 0.05, p = 0.96$	
Positive; at Near	CB	31.7 ± 8.4	34.9 ± 8.1	$t = 1.17, p = 0.27$	$F = 0.00, p = 0.99$
	PM	35.0 ± 6.1	34.6 ± 5.9	$t = -0.14, p = 0.89$	
Negative; at Distance	CB	11.1 ± 3.5	10.5 ± 2.5	$t = -0.39, p = 0.70$	$F = 0.42, p=0.53$
	PM	12.1 ± 4.8	11.5 ± 3.7	$t = -0.48, p = 0.64$	
Negative; at Near	CB	13.8 ± 4.7	15.2 ± 4.2	$t = 0.64, p = 0.54$	$F = 0.56, p = 0.46$
	PM	16.5 ± 5.2	16.5 ± 4.3	$t = 0.06, p = 0.95$	
Vergence Facility	CB	9.3 ± 5.2	10.6 ± 4.2	$t = 0.86, p = 0.41$	$F = 0.97, p = 0.34$
	PM	11.2 ± 4.7	9.6 ± 5.3	$t = -0.99, p = 0.34$	

[a] Training Groups: CB = Combined training Group; PM = Perceptual-motor Group
[b] Statistically significant difference were bolded

Table 3. The visual perceptual skills and handwriting speed in the combined training group and perceptual-motor group 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 [e]	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	
Errors 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] Developmental eye movement test
[d] The Beery-Buktenica developmental test of visual motor integration
[e] Statistically significant differences were bolded

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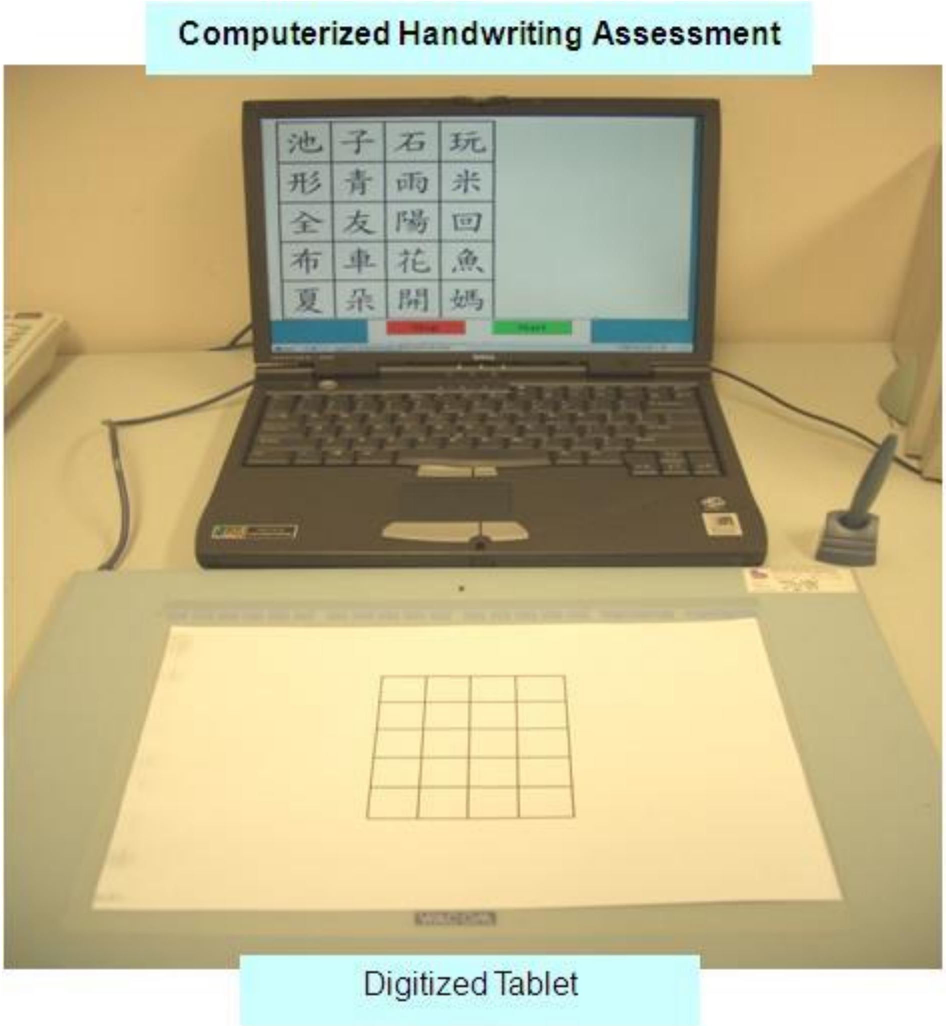

Figure 1. This figure shows the setup of the computerized handwriting assessment tool

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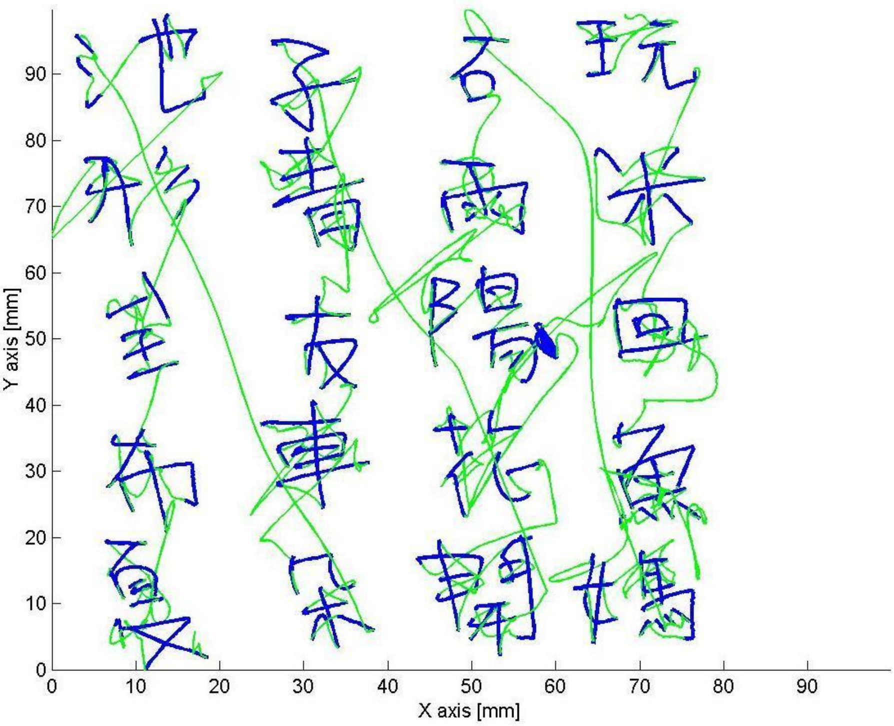

Figure 2: This figure shows the pre-training handwriting sample of a participant captured by the computerized handwriting assessment tool. The Blue line marked the trajectory of the pen in direct contact with the writing surface while the green line marked the trajectory of the pen in air during the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

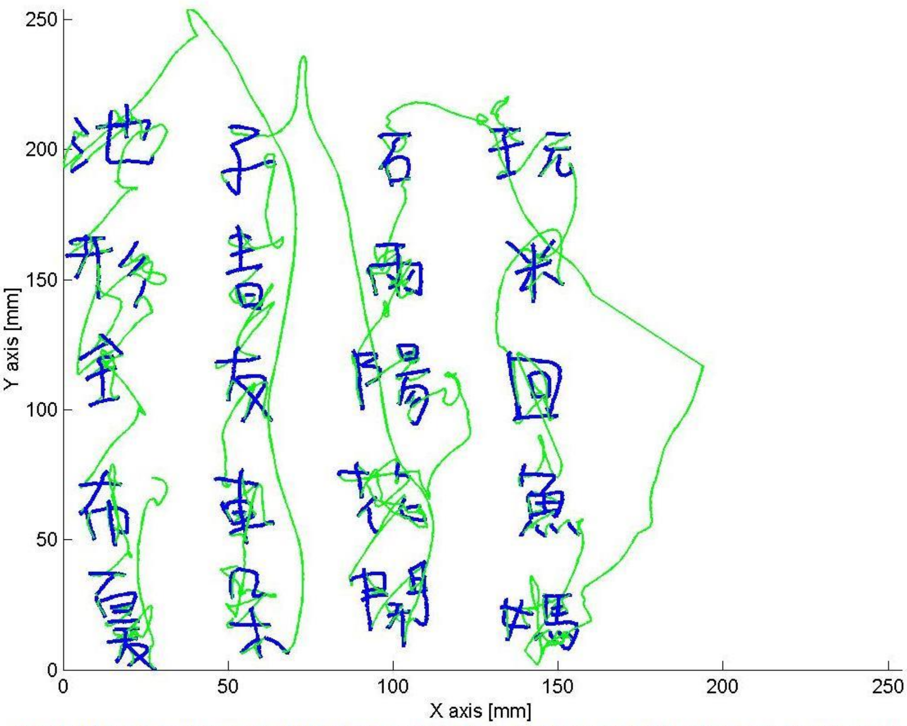

Figure 3: This figure shows the post-training handwriting sample of a participant captured by the computerized handwriting assessment tool. The Blue line marked the trajectory of the pen in direct contact with the writing surface while the green line marked the trajectory of the pen in air during the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

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