

The Effect of Motor Learning Based Computer-Assisted Practice for Children with Handwriting Deficit – Comparing with the Effect of Traditional Sensorimotor Approach

Shao-Hsia Chang, Nan-Ying Yu

Abstract—The objective of this study was to test how advanced digital technology enables a more effective training on the handwriting of children with handwriting deficit. This study implemented the graphomotor apparatuses to a computer-assisted instruction system. In a randomized controlled trial, the experiments for verifying the intervention effect were conducted. Forty two children with handwriting deficit were assigned to computer-assisted instruction, sensorimotor training or control (no intervention) group. Handwriting performance was measured using the Elementary reading/writing test and computerized handwriting evaluation before and after 6 weeks of intervention. Analysis of variance of change scores were conducted to show whether statistically significant difference across the three groups. Significant difference was found among three groups. Computer group shows significant difference from the other two groups. Significance was denoted in near-point, far-point copy, dictation test, and writing from phonetic symbols. Writing speed and mean stroke velocity in near-, far-point and short paragraph copy were found significantly difference among three groups. Computer group shows significant improvement from the other groups. For clinicians and school teachers, the results of this study provide a motor control based insight for the improvement of handwriting difficulties.

Keywords—Dysgraphia, computerized handwriting evaluation, sensorimotor program, computer assisted program.

I. INTRODUCTION

HANDWRITING is an essential fine motor skill in school-aged children. Children's ability to produce fluent and legible script is important for expressing, communicating and recording ideas as well as for educational development, achievement in school and self-esteem [1], [2]. This skill is directly related to most school activities. From a survey of the activities in an elementary school classroom, 30% to 60% of the time is spent in fine motor activities, with handwriting predominating over other tasks [3]. From surveys on occupational therapy service in elementary schools, the most common referrals were handwriting problems [4].

Although children with normal development can learn how to write through traditional training between ages six to seven, handwriting is actually a very complicated skill. Neat and

smooth handwriting requires the maturity and integration of cognition, visual perception and fine motor skills [2], [5], [6]. Levine et al. (1981) found that 72% of children with low academic achievement were considered to have difficulty with fine motor tasks for such dysfunctions on relevant items in the parent and/or teacher questionnaires (e.g., using a pencil, putting things together, etc) [7].

From 1980's, the kinesthetic training approach was firstly proposed and found to have positive results in handwriting remediation [8]; however, research by Sudsawad et al. (2002) to examine the effect of kinesthetic training on handwriting performance in first graders did not successfully link kinesthesia and handwriting, placing the previous theory proposed by Laszlo and Bairstow (1984) into question [9]. Up until now, handwriting practice incorporating motor-learning principles with evidence support did show promising improvement resulting from intervention [10], [11].

In 1980's, a computer-assisted handwriting exercises which offer significant advantages over more conventional teaching techniques was described. Lally (1982) considered handwriting as a skill that must be regulated by processes which at first are externally controlled but which become internalized as the learner becomes more proficient at the skill. Handwriting samples of lower-case alphanumeric characters were obtained from nine mentally retarded school children. After a training program spread over a period of four weeks (approximately 5 hours in total), the greatest improvement in handwriting ability occurred where the constraints of the computer-assisted handwriting exercises encouraged students to gradually transfer control of letter formation from computer-mediated cues to more internal ones. These results are discussed in terms of control functions and the acquisition of skilled behavior [12].

From 1990's, numerous methods to teach or improve children's handwriting exist. The approach of improving functional abilities of children with motor learning difficulties has gained popularity in clinical practice. In a recent work of Denton et al. (2006), the effects of sensorimotor based intervention versus therapeutic practice on improving handwriting performance were studied [13]. A comparison of the means for the two groups and control group showed a significant difference in mean scores between sensorimotor and therapeutic program group. After collapsing all three handwriting scales, there is a 95% level of confidence that the

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handwriting performance of sensorimotor group declined between 3 and 14 points. The handwriting performance of therapeutic program group increased between 1 and 12 points. The implications of this study for clinical practice are careful assessment of handwriting and interventions focusing on motor learning principles vs. sensorimotor interventions.

With the help of computerized evaluation, the major finding of our previous study was that the non-proficient hand-writers performed to a significantly inferior degree to the matched samples, especially on the pause time per stroke and the number of changes of direction of velocity. These differences were apparent when the participants engaged in the complex task (short paragraph copying). By linking the results with neuromotor control theories, it was determined that children with poor penmanship have difficulties in the fine motor control which is required for fluent handwriting. The concept of computerized handwriting remediation is therefore introduced. A computer program providing realtime kinematic and kinetic information may improve the handwriting fluency on the basis of motor control.

To date, perceptual function, motor planning and motor control have been paid more attention in the field of handwriting study. For the intervention of sensorimotor approach, several evidences showed the program incorporating task-oriented and self-instruction program providing promising effect [11]. The advance of computer technology also provided an interesting and motivated program. A clinical evidence has been provided to show its effectiveness in more than three decades ago [12]. However, no recent data is available. From the above conceptions, we aim to compare these two different intervention programs. The first objective of this study is to develop a sensorimotor program for children with handwriting difficulty and test its effectiveness on of children with handwriting deficit. The second objective of this study was to show how advanced digital technology enables a more effective training on the handwriting of children with handwriting deficit.

II. METHODS

A. Measurements for Subject Recruitment

1. The Chinese Handwriting Evaluation Questionnaire (CHEQ)

The CHEQ, with a total 29 items, was designed for a diagnostic purpose in regard to Chinese handwriting problems. In the reliability analyses, Cronbach's was .93 for the total 29 items. The internal consistency was confirmed at a high level. The coefficient of the test-retest reliability was determined as .79 ($p < .01$). In the test of construct validity, factor analysis was conducted, revealing six major dimensions: legibility, accuracy, speed, pencil grip, gross movement and attitude [14]. According to the test manual, since 365 out of all the 374 poor hand-writers (97.59%) referred by their teachers had more than two of the six dimensions with a median larger than 3, it became a cutoff criterion for the identification of handwriting deficit.

2. The Elementary Reading and Writing Test

This test is a standardized Chinese handwriting performance test. It is composed of 7 subtests, including: Word choice from a phrase, Word choice from listening to a phrase, Writing from denotative symbols, Dictation test, Word pronouncing, Phrasing from a word, Far-point copy and 2 complementary tests: Near-point copy and Short paragraph copy [15]. To eliminate the possibility of excessive evaluation of the achievement of academic learning, only Writing from denotative symbols, dictation test, the Far-point copy and the two complementary tests (Near-point and Short paragraph copy) were adopted to administer to the children. Handwriting deficit was indicated as all the scores of the three tests being lower than the score of the 20th percentile. This test is not only for subject recruitment but also for measuring the effect of intervention and for the follow up.

B. Measures for the Evaluation of Handwriting Function

1. Computerized Handwriting Function Evaluation

In addition to Elementary Reading and Writing Test, computerized handwriting function evaluation is also conducted for the evaluation of handwriting function before and after the intervention program. The following is the description of protocol for computerized handwriting function evaluation.

(1) Measuring Instruments

In the computerized handwriting test, a digital tablet was used to collect the trace and temporal data of handwriting movement for further kinematic and kinetic analyses. The handwriting tasks were performed on an A4 size paper affixed to the surface of a 2-D digitizing tablet (Wacom, Intuos 4, Japan) using a wireless electronic inked pen with force sensitive tip (1024 levels). The digital tablet samples the X (horizontal) and Y (vertical) positions of the pen tip as well as the axial pen force, with a maximum frequency of 200 Hz, a spatial accuracy of .01 cm, and a temporal accuracy of 1 ms. The top panel of the tablet is an electronic surface that records the position only when the pen comes in contact with its surface or within 10 mm of its surface. The pen used in this study is of a size and weight similar to that of pens typically used by children of this age (length = 150 mm, circumference = 35mm, weight = 11gm). Due to the portability of the digitizing tablet and a notebook computer, all these measures were employed in the child's natural classroom environment without interference from other persons.

(2) Handwriting Tasks

For measuring near- and far-point copy tests, an A4-sized paper will be placed on the digital tablet. In an arrangement of 6 rows and 5 columns (30 grid cells), every grid cell had a size of 18*18 mm. The task of short paragraph copy will be performed on an A4-sized sheet in an arrangement of 10 columns with a width of 18 mm. The subjects were instructed to copy the testing task on the test sheet from the right top. They were told that they should write as fast and correctly as possible. The task is constrained in time for 2 min in near- and far-point copy tasks

and 4 min in short paragraph copy. The examiner gave instructions and monitored the practice process. After confirmation that the child know how to proceed, the measurement starts. The whole process will be recorded and the data will be saved into a computer hard disk for further offline analysis.

(3) Measuring Parameters of Computerized Analysis

After surveying the results of related researches and the results and experiences of our previous studies, the following parameters were chosen for the evaluation of the handwriting process. The parameters were obtained directly from the kinematic or kinetic data, or derived from the temporal or spatial data of the pen-tip movement. The parameters included: (1) mean stroke velocity, (2) mean axial pen tip force, (3) pause time per stroke, and (4) number of changes of direction of velocity. The following are the operative definitions of the parameters processed from the registered coordinates and axial pen force.

1. Mean Stroke Velocity: The stroke velocity was determined by dividing the stroke length by the elapsed time. The mean value was derived from the average of all the strokes in all of the written tasks.
2. Mean Axial Pen Force: The axial pen force in the middle 8/10 of a stroke (ex. middle 4 mm of a 5-mm stroke) was recorded. The mean value was determined by dividing the sum of these values by the total number of sampling points in a task.
3. Number of Changes of direction of Velocity: The number of vertical (or horizontal) velocity peaks for every vertical (or horizontal) stroke was determined as an approximation of the number of changes of direction of velocity, and represents the level of automation. The number of changes of direction of velocity per stroke decreases as movement becomes automatic; otherwise movement remains deliberate. When movement is fully automated, the ideal number of changes of direction of velocity per stroke is 1 per vertical or horizontal stroke; a decrease in the number indicates a switch from closed feedback control to open loop control.
4. Pause Time per Stroke: In the case of two consecutive sampling points having the same registered coordinate, it is considered as a pause period. This parameter is derived from dividing the cumulative pause time period by the total stroke number.

B. Subject Recruitment

The subject recruitment consisted of a two-step process. The first step was to screen children with handwriting deficits by the referral of teachers in 3 public elementary schools in the Kaohsiung area using Chinese Handwriting Evaluation Questionnaire (CHEQ). Children were excluded from this study when they reported a history of any medical, neurological or pervasive developmental disorders, intellectual disability, oncological, musculoskeletal, sensory (hearing, vision) or skin disorders. From the first and second graders, children meet the screening criteria were followed by the administration of an Elementary Reading/Writing Test; children with handwriting deficits were identified and then recruited into this study as the

study group. For recruiting matched children as the control group, typically developing children without handwriting deficits were also recruited. In regard to their matching the study group, they were recruited randomly from the same classes as the children who are in the study group. In addition, they were matched with the study group in regard to factors such as: gender, age and preferred hand. Since all the participants come from public schools in the same district, handwriting in the Chinese Language lessons is instructed from Grade 1. The textbooks and curriculum used and the total studying hours are identical in every class. In this study, 21 first- and 21 second-grade students who had scored below the 21st percentile on the elementary read/ writing test were recruited from schools in Kaohsiung area. The children were randomly divided into computer program, sensorimotor program and control group. Every group has 14 subjects with matched age and gender. Before and after the intervention, tests for handwriting performance were administered to the three groups.

C. Procedure

1. Computer-Based Instruction Handwriting Instruction

All participants performed the experiment under similar environmental conditions in a quiet classroom which was designed for children with special need in their school. Each participant was given the instruction individually during the morning hours. The participants were seated on a standard school chair and in front of a standard school desk which are appropriate to his or her age and height. The tasks were written on normal writing paper with printed lineation, which is affixed to the digitizing tablet. Each participant was instructed in the same fashion about what he or she should be required to do. The program usually takes approximately 45 minutes. In the experiment, the displacement of pen tip can be monitored and recorded by a computer program running on Windows XP. The participants' writing trace was displayed in real time on the display of notebook computer, 60 cm in front of them. Fig. 1 shows the display for the beginning of program. Fig. 1 shows an example of computer program for handwriting instruction. The indicative parameters are displayed for a positive feedback and reinforcement. It can provide the results of deterministic parameters for the evaluation of handwriting movement control.

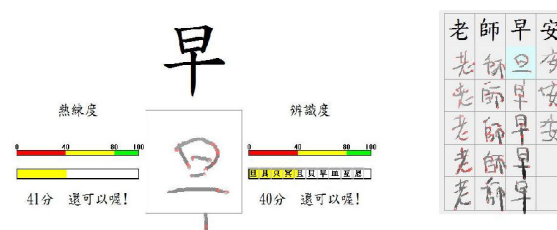


Fig. 1 An example of computer program for handwriting instruction. Center of display shows the performance scores. The proficiency scores 41. Legibility scores 40. Strokes with black (red) color denote fluent (dysfluent) movement. Strokes with dark shade denote greater pressure were applied. Right grids display the handwriting trajectory

2. Sensorimotor Training

An experienced pediatric occupational therapist (first author) provided advice on appropriate therapeutic intervention strategies. In each session, a sensorimotor component was addressed for 40 minutes over a week of three sessions (i.e., two hours total intervention time for each week). For all the recommended sensorimotor components, there was a total of 12 hours in 6 weeks during the entire study. Treating therapists were supplied with a toolbox of games, activities work sheets, equipment, treatment ideas for each component, as well as the schedule for rotation of activities.

3. Control Group

Children in the control group continued to have their handwriting training by their teachers at school which was mainly remedial handwriting exercises. All participants in both groups were evaluated at pre-test and post-test on their handwriting skills, visual-motor integration and visual perception skills using the standardized instruments by experienced occupational therapists.

D. Statistical Analyses

MANOVA analyses were used to test for the group differences (intervention versus control groups) for each dependent variable. To examine the source of the significant differences between groups, the data from each task were subjected to univariate ANOVAs. Paired *t* test with repeated measures were utilized to compare the difference before and after intervention.

III. RESULTS AND DISCUSSIONS

Analysis of variance of change scores were conducted to show whether statistically significant difference across the three groups. Significant difference was found among three groups ($p < .01$). Computer group shows significant difference from the other two groups. Significance was denoted in near-point, far-point copy, dictation test, and writing from phonetic symbols.

Table I shows the results of handwriting performance evaluation. Subjects in computer group showed significant improvement in the scores of Writing from denotative phonetics, Total score in handwriting, Near point copy, and Short paragraph copy. Subjects in sensorimotor and control group only showed significant improvement in the scores of Writing from denotative phonetics. The results of repeated measures ANOVA showed the statistical significance in Near point copy. It indicated significant interaction of group and intervention in the improvement of Near point copy.

TABLE I
THE MEANS (SD) OF SCORES IN ELEMENTARY READ/WRITE TEST

Groups	Writing from denotative phonetics	Total score in handwriting	Near point copy	Short paragraph copy
Com (before)	12.6(6.6)♦	47.5(6.9)♦	9.5 (5.2)*	25.9(13.1)*
Com (after)	17.2(6.4)	52.8(8.6)	12.2 (5.0)	34.2(10.9)
Sen (before)	10.0 (6.4)♦	47.4 (6.5)	10.9(5.6)	35.2(26.0)
Sen (after)	14.9(6.1)	48.1(7.2)	11.8(6.3)	34.5(17.4)
Con (before)	9.1 (7.2)*	41.8 (15.1)	9.3(5.4)	23.4(14.0)
Con (after)	12.3(7.8)	41.9 (7.4)	7.4(3.8)	27.7(16.0)
Differences among three groups	$F=1.04$, $p=0.36$	$F=1.21$, $p=.31$	$F=6.11$, $p=.005$	$F=2.02$ $p=.146$

Com: computer group, Sen: sensorimotor group, Con: Control group
+ $p < .05$; * $p < .01$; ♦ $p < .001$

Tables II and III show the results of handwriting fluency tests. From mean pause time and peak velocity, the computer assisted group shows significant improvement in all tests for handwriting fluency. Subjects in sensorimotor and control group did not show any significant improvement in these measures. The results of repeated measures ANOVA show the statistical significance in all variables except mean peak velocity in short paragraph copy. It indicated significant interaction of group and intervention in the improvement of these tests.

TABLE II
THE RESULTS OF COMPUTERIZED HANDWRITING TEST (MEAN PAUSE TIME PER STROKE)

Groups	Near point copy	Far point copy	Short paragraph copy
Com (before)	187.6 (78.7)♦	213.2(66.1)♦	181.9(66.9)*
Com (after)	129.8 (52.4)	158.8(58.5)	148.7(54.4)
Sen (before)	168.6 (22.0)	210.3(54.7)	179.6(38.8)
Sen (after)	173.8 (64.9)	192.9(41.1)	182.0(39.5)
Con (before)	191.7 (33.4)	230.7(47.4)	193.1(52.1)
Con (after)	179.7 (42.0)	210.0(38.8)	179.5(66.2)
Differences among three groups	$F=6.411$ $p=.004$	$F=3.685$ $p=.034$	$F=4.113$ $p=.024$
	Com>Sen Com>Con	Com>Sen Com>Con	Com>Sen Com>Con

Com: computer group, Sen: sensorimotor group, Con: Control group
+ $p < .05$; * $p < .01$; ♦ $p < .001$

TABLE III
THE RESULTS OF COMPUTERIZED HANDWRITING TEST (MEAN VELOCITY PEAK PER STROKE)

Groups	Near point copy	Far point copy	Short paragraph copy
Com (before)	3.07(.89)*	3.11(.82) ♦	2.70(.85)+
Com (after)	2.43(.73)	2.25(.45)	2.34(.53)
Sen (before)	2.92(.33)	3.37(.77)	2.63(.53)
Sen (after)	3.00(.71)	3.04(.72)	2.49(.72)
Con (before)	2.98(.80)	3.23(.51)	2.91(.52)
Con (after)	2.74(.82)	3.18(.65)	2.99(.43)
Differences among three groups	$F=3.705$, $p=0.034$	$F=5.384$, $p=0.009$	$F=2.23$ $p=0.121$

Com: computer group, Sen: sensorimotor group, Con: Control group
+ $p < .05$; * $p < .01$; ♦ $p < .001$

Table IV shows the comparison between before and after intervention in mean axial pen force during three copy tasks. Computer group showed significant improvement in mean

axial pen force in all tasks. Sensorimotor and control groups did not show any significant changes in the three tasks.

TABLE IV
THE RESULT OF COMPUTERIZED HANDWRITING TEST (MEAN PEN TIP PRESSURE)

Groups	Near point copy	Far point copy	Short paragraph copy
Com (before)	711.4 (100.9)*	704.6 (72.2)+	707.7 (74.4)+
Com (after)	760.8 (104.7)	755.1 (109.4)	748.2 (84.5)
Sen (before)	728.6 (99.1)	700.8 (37.3)	713.6 (99.5)
Sen (after)	738.1 (109.9)	723.8 (45.1)	725.9 (92.8)
Con (before)	697.2 (107.2)	702.2 (134.3)	694.7 (88.8)
Con (after)	725.7 (118.6)	719.7 (110.8)	709.6 (119.4)
Differences among three groups	F=1.081, P=0.349	F=.877 p=.424	F=.465 p=.632

Com: computer group, Sen: sensorimotor group, Con: Control group
+ $p < .05$; * $p < .01$; ♦ $p < .001$

IV. DISCUSSIONS

Based on motor control theory of handwriting movement, this study developed a computer program to implement the feedback protocol to enhance the stability and fluency of handwriting. The results show the computer program can improve the handwriting performance significantly. In the computer program, realtime feedback of the stroke velocity can improve the problem of long pause of pen tip movement. Immediate auditory feedback of stroke velocity and axial pen force reduce the load of multitask attention. After the completion of a character, the summary for fluency and legibility evaluation provide basis for next practice. It explains why major improvements on stroke velocity and handwriting speed.

In view of planning effective intervention to improve motor control of handwriting, the proper employment of both phasic and tonic stiffness is required [16]; however, in the opinion of Smits-Engelsman et al., the strategy of maintaining tonic stiffness by increasing axial pen force is not always suggested. Increasing axial pen force requires more muscle force, which increases neuromotor noise or muscle fatigue and may have harmful effects on the muscles of the upper limbs [17]. When a child is first beginning to learn a new letter, tonic muscle activities may be introduced with brief bursts of co-contraction followed by a gradual reduction of grip force through the use of verbal and/or physical prompts or cueing. In the intervention program, children with dysgraphia were encouraged to increase the axial pen force. They did apply more force on paper.

Both tonic and phasic stabilities were maintained. Our previous study found that less axial pen force was applied by children in writing complex characters. This interesting finding might be attributed to the fact that complex characters require more than a few short strokes, more lifting of the pen, and a larger number of pauses on the paper [18]. Also, a larger reduction of mean axial pen force was significantly noted in the complex writing tasks of the group with handwriting deficit. This finding was similar to the results of Rosenblum et al.'s work (2008) which demonstrated that DCD children exert less pressure when writing [19].

In summary, this study proved the feasibility of applying computer assisted program in Chinese handwriting training for children with dysgraphia. The handwriting performance in sensorimotor and control groups also shows improvement in the period of intervention. However the improvement did not show significant. For clinicians or school teachers, the results of this study provide a motor control based insight for the improvement of handwriting difficulties.

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