Published in final edited form as:

J Child Neurol. 2010 June ; 25(6): 674–680. doi:10.1177/0883073809342592.

Increasing viscosity and inertia using a robotically-controlled pen improves handwriting in children

Hilla Ben-Pazi, MD,

Neuropediatric Unit, Shaare Zedek Medical Center, Jerusalem, Israel and Department of Child Neurology, Stanford Medical Center, Stanford CA, USA

Abraham Ishihara, MS,

Department of Child Neurology, Stanford Medical Center, Stanford CA, USA

Sahana Kukke, MS, and

Department of Child Neurology, Stanford Medical Center, Stanford CA, USA

Terence D Sanger, MD PhD

Department of Child Neurology, Stanford Medical Center, Stanford CA, USA

Abstract

The aim of this study was to determine the effect of mechanical properties of the pen on the quality of handwriting in children.

Twenty two school aged children, ages 8–14 years wrote in cursive using a pen attached to a robot. The robot was programmed to increase the effective weight (inertia) and stiffness (viscosity) of the pen. Speed, frequency, variability, and quality of the two handwriting samples were compared.

Increased inertia and viscosity improved handwriting quality in 85% of children ($p < 0.05$). Handwriting quality did not correlate with changes in speed, suggesting that improvement was not due to reduced speed. Measures of movement variability remained unchanged, suggesting that improvement was not due to mechanical smoothing of pen movement by the robot. Since improvement was not explained by reduced speed or mechanical smoothing, we conclude that children alter handwriting movements in response to pen mechanics. Altered movement could be caused by changes in proprioceptive sensory feedback.

Keywords

handwriting; dysgraphia; rhythmic movement; robot

Handwriting is a complex motor task that remains an imperative skill despite the wide availability of computers.¹ Adequate learning and practice is essential for achieving proficiency;² 30% to 60% of elementary school day is allocated to fine motor activities, with writing tasks predominating over other manipulative tasks.³ Although penmanship is systematically taught,² 12–20% of elementary school-aged children have difficulty with handwriting,⁴ affecting academic achievement.⁵ This subgroup of children is often referred for therapeutic intervention.^{6,7}

Different methods are used for improving poor penmanship. While clinical evaluation and interventions are extensively reported in the literature^{8–11}, the neuronal underpinnings of this complex motor skill remain unclear.^{12–14} Physical therapy improves serious handwriting problems accompanied by fine motor deficits.¹⁵ Practice is the main intervention described in the literature.^{8,16} Unfortunately, studies of handwriting practice often fail to explain the underlying pathology¹⁷, since the studies seldom specify the exact impairment¹⁸ and precise therapeutic method^{8,19}.

An alternative way to study handwriting is to introduce a perturbation and examine the resulting change in movement.²⁰ In this study we used a robot manipulandum attached to the pen in order to increase the apparent inertia and viscosity of the pen (figure 1). A robotic manipulandum allows a pen with arbitrary dynamics to be simulated and the results analyzed digitally. Robot manipulation of handwriting has not previously been studied, although robots have been used to improve arm movement following acute²¹ and chronic²² stroke in adults. This improvement was attributed to change of somatosensory input.²²

An important advantage of the use of a robot is that the viscosity of the pen tangential to the writing surface can be increased without increasing the downward force of the pen. This is essential so that the effect of viscosity can be studied without requiring increased hand strength to support the weight of the pen against gravity. Therefore inertia and viscosity were changed only in the directions tangential to the writing surface.

The quality of handwriting is determined by both the central neurologic movement commands as well as the biomechanics of the arm, hand, and pen. We investigate the effect of the changed pen dynamics on movement commands. If the movement commands are pre-programmed feedforward commands that are independent of sensory input, then the effect of increased inertia and viscosity will be slower, smoother, and less accurate handwriting. If the movement commands can sense the pen dynamics and completely compensate for the changes, then increased inertia and viscosity will have no effect on handwriting quality. We hypothesize that movement commands respond to changes in sensation due to the pen dynamics, but that the commands can only partly compensate for the changes. Therefore we predict that children may have either improved or worsened handwriting using the robot, but writing will not be slower.

Since it has been demonstrated that children with poor handwriting have increased variability in the pen trajectory,²³ we speculated that improvement in handwriting might be associated with a decrease in trajectory variability. In this study, we determine the effect of an increase in pen inertia and viscosity on the speed, quality, and variability of handwriting in children.

Methods

Subjects

Twenty two school aged children, 8–14 years of age (mean 11.1 years (SD 1.4); 12 boys, 10 girls; 19 right-handed, 3 left-handed) participated. Inclusion criteria were regular school attendance and proficiency in cursive writing. Children in the special education program or with a neurological or medical condition impairing the ability to follow tasks were excluded. 26 children were referred; four were excluded due to age (n=2), unskilled cursive handwriting (n=1) and incompleteness of the robot task (n=1). Some participants had neurological disorders that did not interfere with the ability to perform the tasks. In particular, they were: developmental coordination disorder (n=3) and attention deficit disorder (n=1). None of the children were on concurrent medication. The study was approved by the Stanford University Institutional Review Board and all parents signed written informed consent.

Testing procedure

Each child was comfortably seated in a quiet room at the Stanford pediatric movement disorders laboratory. All data were collected by a single examiner (HBP). The participants used their preferred writing hand for all tasks. Three participants wrote with their left hand and 19 with their right hand. The session lasted an hour with a break if needed, and consisted of 3 parts pseudo-randomly ordered between different subjects:

1. **Digitized Tablet:** A digitized tablet and an inking pen (Intuos 2 – *XD0912R*, Wacom, Saitama, Japan) were used to record pen tip position during handwriting. Data were collected using a program written in Visual Basic 6.0 (Microsoft, Redmond, WA, USA) and sampled at 100 Hz. Participants were instructed to write continuous cursive L's on a lined sheet of paper (lines spaced 1 cm apart) placed on the tablet (figure 1). The last 14 participants were requested also to write the following sentence: "Mommy and daddy had lunch on Monday". This sentence was chosen because it uses words without the letters i, j, and t, allowing continuous handwriting. Each task (L's and sentence) was repeated 5 times, in pseudo-random order. This part lasted 10–20 minutes.
2. **Scrolling Screen:** In order to collect longer segments of continuous handwriting, a tablet PC (Fujitsu LifeBook *T4010*, Tokyo Japan) was programmed to display a scrolling screen for use during writing with a stylus. The position of the stylus tip was recorded with a sampling rate of 133 Hz. The scrolling screen was designed as an enlarged notebook row with three lines across, spaced 1 cm apart. The upper and lower lines were dark blue while the middle was light blue. The participants were instructed to write on the lowest line. While the screen scrolled to the left at a velocity of 8 mm/second, small vertical lines appeared on the top of the scrolling screen, giving the children a sense of the scrolling speed. Fourteen of the 23 children performed the scrolling screen part. Two tasks (L's and sentence) were performed 5 times in a random manner. This part lasted 15–20 min.

Both the inking pen and the stylus were attached near the pen tip to the end of a Phantom 1.5 robotic arm (SensAble Technologies, Cambridge, MA) (picture 1). The robot simulated an inertial force of a 500g mass in the horizontal plane. Additionally, we added a viscosity term of 0.07 (N s/m). We did not simulate any frictional forces, although the pen tablet provided a small amount of static friction. A constant downward vertical force of 1 Newton (equivalent to 102 grams) was simulated so that the pen would not spontaneously lift off the writing surface.

For safety, the child's upper body was separated from the robot by a transparent shield so that only the writing hand was within the robot work space. For each trial the horizontal simulated viscosity and inertia were set pseudo-randomly either as specified above, or to zero to provide a comparison with baseline.

Data analysis

Improvement: we used 2 measures to assess improvement of handwriting sample: teacher's scores and lay rating. Six participants' were assessed by lay rating but were not evaluated by the teachers. For each method we used different handwriting samples:

1. **Teacher scores:** Two experienced elementary school teachers rated the participants' sentence samples. Teachers rated handwriting with and without a robot (spontaneous handwriting) for each participant, in a randomized blinded manner; they were not aware of whether the robot was on or off for each sample. They rated each sample according to what was expected for their age by making a mark on a 10 cm line (linear analog scale). One end of the line indicated "extremely poor" and the other

“outstanding”. The intraclass correlation between the two teacher raters was 0.75. Ratings were rescaled from 0 (the lowest) to 100 (the highest grade) for each teacher; the rating score was the average of the rescaled rates of the 2 teachers. Consequently each child had a teacher rating score, expressed as a percentage. Difference in teacher scores (score when writing with the robot on minus the score for spontaneous handwriting) indicated the degree of improvement; the larger number the greater the improvement (figure 3).

2. Lay rating: Improvement of handwriting was assessed by 4 lay raters. Samples of spontaneous and robot handwriting samples were randomly ordered as “A” or “B”. Each rater was asked to mark the place on a 10 cm line that best describes the difference between the 2 handwriting samples. The center of the line indicated no change while the edges of the line were marked “A much better than B” and the other “B much better than A”. For each child at least 2 handwriting samples were used, L’s and sentence. The mean interclass correlation was 0.68 between the lay raters. The lay ratings were rescaled from 0 to 100% and then averaged for each child. Improvement was presented as a percent so that a change of greater than 50% indicates that the robot improved handwriting. Although the rates of lay evaluators are represented similarly to the teachers’ score, the evaluation method was different from the teachers’. Furthermore the lay raters evaluated both L’s and sentences while the teacher’s evaluated sentence samples only. The teachers were requested to rate the sample according to age while lay raters, who were inexperienced in children’s handwriting assessment, were requested to compare the 2 samples.

Temporal data analysis—All data analysis was performed using MatLab 7.0.4 (Mathworks Inc., Natick, MA, USA).

Handwriting spectral analysis, was performed on all continuous segments longer than 600 ms in order to track frequency components from 1.7 –5 Hz. The Fast Fourier Transform (FFT) was applied to each segment of L’s and words (figure 3b, e) as follows. The first 100 ms of each segment were not included in the analysis. The segments were visually scanned and cropped to exclude technical artifacts or distinct periods without writing. For each segment an FFT was performed. Given that the segments differed in duration, all segments were resampled to 1000 points and then averaged. For each participant there were 8 different writing tasks: digitized tablet L’s (robot off and on), scrolling tablet L’s (robot off and on), digitized tablet sentences (robot off and on) and scrolling tablet sentences (robot off and on).

Given that both the X-axis (left and right) and Y axis (down and up) had the same FFT profile and that the Y-axis kinematic profile is commonly used for handwriting analysis²³, all temporal analyses were computed from data in the Y-axis. We used the same analysis for both the digital tablet and the scrolling screen since scrolling velocity did not affect the Y-axis display or recordings.

Two main parameters were retrieved from each FFT: the mean frequency of the handwriting task and the variation of the frequency (the area under the FFT plot). The actual temporal values calculated for each child were mean frequency and coefficient of variation (CV). Taken that temporal variability decreases with frequency, we used the CV, defined as the standard deviation divided by the mean frequency, as a normalized measure of temporal variability.

Linear correlation between scores of spontaneous handwriting and the improvement with the robot was performed after removing outliers ($\pm 2SD$) by calculating the correlation coefficient and p-value (MatLab ‘corrcoef’). We used a 95% confidence interval for all statistical methods to quantify uncertainty and results were reported as significant for $p < 0.05$.

Results

Qualitative assessment- Teacher and lay raters scores

Teachers gave a higher score for handwriting samples written with the robot (51%, SD 19) than without it (48%, SD 18; $n=18$, one tailed paired t-test; $p<0.05$) with a mean improvement of 4% (SD 5.5%). The lay raters' comparison of two handwriting samples showed an overall improvement when using the robot (11% of improvement, SD 14). The improvement was more prominent when writing L's (16%, SD 16) than when writing sentences (1%, SD 16). Since the difference between the lay raters' comparisons for L's and sentences was not significant ($n=14$, two tailed t-test; $p=0.29$), the improvement scores of both tasks were analyzed together. Improvement in handwriting occurred in 85% children (22/26) ranging (3–41%). Lay rating of improvement writing L's did not correlate with the rating of sentences ($n=16$, $R=-0.3$, $p=0.3$). There was no correlation found between teacher's scores and lay ratings ($n=16$, $R=-0.3$, $p=0.3$), even when examined for the sentences only ($n=12$, $R=-0.15$, $p=0.6$).

Post-hoc analysis showed no significant correlation between scores of spontaneous handwriting and the improvement with the robot (for teachers $n=17$, $R=-0.02$, $P=0.94$; lay $n=18$, $R=-0.25$, $P=0.31$), indicating that the improvement did not depend on whether the child had good or poor handwriting. There was no association between improvement and age ($n=15$, $R=-0.02$, $P=0.93$) or gender (two tailed t-test; $p=0.07-0.9$).

Quantitative analysis

The robot changed the mean frequency of handwriting (e.g. writing L's on the digitalized tablet was at 1.9 ± 0.4 Hz with the robot on versus 2.3 ± 0.4 Hz when it was off; table 1a). While, in general, children wrote at a slower rate with the robot (table 1a), some (6/22) children wrote faster with the robot when writing L's, indicating that the children could potentially write at a faster frequency despite the robot (with robot on 1.6 ± 2.2 Hz versus 1.5 ± 1.6 Hz with the robot off; one tailed paired t-test, $p<0.01$). The coefficient of variation (CV), on the other hand, did not change significantly with the robot force field, and remained constant throughout the specific task (table 1a). These temporal characteristics were demonstrated both for writing L's and sentences. However when changing special and temporal properties of the task, by switching from the digitized tablet to the scrolling tablet, the frequency of handwriting and CV remained generally constant (table 1b). Letter height of L's did not change significantly with the robot that supports the contention that the motor command must have changed.

Post-hoc analysis of predictors of improved handwriting did not show any correlation between handwriting improvement and age, gender, mean handwriting frequency, mean pen speed. Improvement of handwriting did not correlate with baseline writing frequency ($p=0.6-0.9$), frequency change ($p=0.4-0.9$), baseline CV ($p=0.7-0.9$) or CV change ($p=0.1-0.8$).

Discussion

Increasing the horizontal viscosity and inertia of the pen using a robot improved children's handwriting as measured by both experienced teachers and inexperienced lay people. The lack of correlation between the ratings of the teachers and lay are probably due to the different samples used and the different ways of assessment; Other handwriting tests have also failed to demonstrate correlation with teacher questionnaire scores.²⁴ The lack of correlation between the L's and sentences in the lay ratings may be attributed to the fact that these are different assignments.²³ This effect occurred despite the lack of a consistent reduction in handwriting speed, and reduction in handwriting speed did not predict improvement in handwriting quality. Handwriting variability did not change with the robot and the speed changes were inconsistent; some children wrote slower with the robot while others wrote faster.

Improvement in handwriting could be due to the mechanical effect of the robot on motion of the pen, to changes in motor commands due to compensation for the robot, or a combination. If changes in handwriting were only due to the mechanical effect of the pen on an invariant set of forces produced by the hand, then pen movement should have been slower, less variable, and smoother. Since the frequency and variability of handwriting did not change with the robot, our data suggest that compensatory changes in motor command must have occurred. Since the amount of viscosity and inertia added by the robot were equivalent to 26% and 0.7% of the inertia and viscosity of the human arm,²⁵ respectively. The lack of a consistent reduction in writing speed implies that some of the children compensated by increasing drive to muscles in order to overcome the opposing forces from the robot. Our data do not allow us to determine whether improvement in handwriting was a direct effect of the changed motor command, or a combined effect of the changed motor command and the robot mechanics. However, the fact that the handwriting was not identical in the two cases suggests that the motor command is unable to compensate completely for changes in pen dynamics.

A robotic haptic device with increased inertia and viscosity is currently being developed for assessment and therapy of children with developmental coordination disorder.^{26,27} Pemaleté et al (2005) programmed a phantom haptic device, similar to ours, to assist in learning a certain trajectory. Children with developmental coordination disorder were trained to move according to a path, while inertia and viscosity were increased during the whole task. Results were published for only one child that demonstrated improved handwriting skills after the robotic haptic therapy.²⁶

Lockerhart and Law (1994) trained 4 children with poor penmanship and poor sensomotor skills to write on paper with different viscosity properties (writing on paper vs. sandpaper). Handwriting improved, without a change in handwriting speed resembling our results. Additionally, children with poor penmanship apply more pressure when writing.^{28,29} This self-manipulation may add viscosity similar to writing with a robot or writing on sandpaper.³⁰

Therefore our results show (1) handwriting quality improves when pen viscosity and inertia are increased, and (2) the change in handwriting quality cannot be explained only by the mechanical effects of the change in pen properties. Based on these results, we suggest that temporal aspects of handwriting are determined by the child's motor plan or motor command, and changes in the mechanical properties of the pen affect handwriting by modifying the motor commands. In conclusion, we found that increasing the viscosity and inertia of the pen using a robot manipulandum can improve handwriting quality without decreasing handwriting speed. Further work is needed to determine the cause of the improvement in handwriting and to confirm these results in a larger sample. We are hopeful that extension of these results may lead to new methods for improving school performance in children with poor handwriting.

Acknowledgments

We thank Mrs. Baldwin and Mrs. Smith, 3rd grade teachers, Nimitz school, Cupertino, CA, Marina Van-Doornik and Kimberley Murphy for their careful evaluation of handwriting samples; Pat Sita for reading the scale ratings; Johan Van-Doornik, PhD for methodological advice; the children and parents for their time, effort and cooperation.

None of the authors have competing interests.

This study was supported in part by generous grants from the Crowley- Carter Foundation, the Don and Linda Carter Foundation, the American Physicians Fellowship for Medicine in Israel and American Physicians Fellowship for Medicine in Israel.

References

1. Christensen CA. Relationship between orthographic-motor integration and computer use for the production of creative and well-structured written text. *Br J Educ Psychol* 2004;74:551–564. [PubMed: 15530201]
2. Asher AV. Handwriting instruction in elementary schools. *The American journal of occupational therapy* 2006;60:461–471. [PubMed: 16915877]
3. McHale K, Cermak SA. Fine motor activities in elementary school: preliminary findings and provisional implications for children with fine motor problems. *Am J Occup Ther* 1992;46:898–903. [PubMed: 1463061]
4. Rubin N, Henderson SE. Two sides of the same coin: variations in teaching methods and failure to learn to write. *Spec Educ Forward Trends* 1982;9:7–24. [PubMed: 7157059]
5. Cummins A, Piek JP, Dyck MJ. Motor coordination, empathy, and social behaviour in school-aged children. *Dev Med Child Neurol* 2005;47:437–442. [PubMed: 15991862]
6. Hammerschmidt SL, Sudsawad P. Teachers' survey on problems with handwriting: referral, evaluation, and outcomes. *Am J Occup Ther* 2004;58:185–192. [PubMed: 15068154]
7. Baker S, Gersten R, Graham S. Teaching expressive writing to students with learning disabilities: research-based applications and examples. *J Learn Disabil* 2003;36:109–123. discussion 149–150. [PubMed: 15493427]
8. Case-Smith J. Effectiveness of school-based occupational therapy intervention on handwriting. *Am J Occup Ther* 2002;56:17–25. [PubMed: 11833397]
9. Densem JF, Nuthall GA, Bushnell J, Horn J. Effectiveness of a sensory integrative therapy program for children with perceptual-motor deficits. *Journal of learning disabilities* 1989;22:221–229. [PubMed: 2738457]
10. 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 Occup Ther* 2006;60:16–27. [PubMed: 16541981]
11. Marr D, Dimeo SB. Outcomes associated with a summer handwriting course for elementary students. *Am J Occup Ther* 2006;60:10–15. [PubMed: 16541980]
12. Lubrano V, Roux F-E, D'emonet J-F. Writing-specific sites in frontal areas: a cortical stimulation study. *Journal of neurosurgery* 2004;101:787–798. [PubMed: 15540917]
13. Volman MJ, van Schendel BM, Jongmans MJ. Handwriting difficulties in primary school children: a search for underlying mechanisms. *Am J Occup Ther* 2006;60:451–460. [PubMed: 16915876]
14. Paine RW, Grossberg S, Van Gemmert AW. A quantitative evaluation of the AVITEWRITE model of handwriting learning. *Hum Mov Sci* 2004;23:837–860. [PubMed: 15664676]
15. Smits-Engelsman BC, Niemeijer AS, van Galen GP. Fine motor deficiencies in children diagnosed as DCD based on poor grapho-motor ability. *Hum Mov Sci* 2001;20:161–182. [PubMed: 11471395]
16. Swanson HL, Sachse-Lee C. A meta-analysis of single-subject-design intervention research for students with LD. *J Learn Disabil* 2000;33:114–136. [PubMed: 15505942]
17. Berninger VW, Abbott RD, Jones J, et al. Early development of language by hand: composing, reading, listening, and speaking connections; three letter-writing modes; and fast mapping in spelling. *Dev Neuropsychol* 2006;29:61–92. [PubMed: 16390289]
18. Hooper SR, Wakely MB, de Kruif RE, Swartz CW. Aptitude-treatment interactions revisited: effect of metacognitive intervention on subtypes of written expression in elementary school students. *Dev Neuropsychol* 2006;29:217–241. [PubMed: 16390295]
19. Woodward S, Swinth Y. Multisensory approach to handwriting remediation: perceptions of school-based occupational therapists. *The American journal of occupational therapy* 2002;56:305–312. [PubMed: 12058519]
20. Agam Y, Bullock D, Sekuler R. Imitating unfamiliar sequences of connected linear motions. *J Neurophysiol* 2005;94:2832–2843. [PubMed: 16014793]
21. Volpe BT, Krebs HI, Hogan N, Edelstein OL, Diels C, Aisen M. A novel approach to stroke rehabilitation: robot-aided sensorimotor stimulation. *Neurology* 2000;54:1938–1944. [PubMed: 10822433]

22. Ferraro M, Palazzolo JJ, Krol J, Krebs HI, Hogan N, Volpe BT. Robot-aided sensorimotor arm training improves outcome in patients with chronic stroke. *Neurology* 2003;61:1604–1607. [PubMed: 14663051]
23. Ben-Pazi H, Kukke S, Sanger TD. Poor penmanship in children correlates with abnormal rhythmic tapping: a broad functional temporal impairment. *J Child Neurol* 2007;22:543–549. [PubMed: 17690059]
24. Sudsawad P, Trombly CA, Henderson A, Tickle-Degnen L. The relationship between the Evaluation Tool of Children's Handwriting and teachers' perceptions of handwriting legibility. *Am J Occup Ther* 2001;55:518–523. [PubMed: 14601811]
25. Cetin AE, Adli MA. Cooperative control of a human and a robot manipulator for positioning a cart on a frictionless plane. *Mechatronics* 2006;16:461–469.
26. Pernalet, N.; Edwards, S.; Gottipati, R.; Tipple, J.; Kolipakam, V. Eye-Hand Coordination Assessment/Therapy Using a Robotic Haptic Device. 9th International Conference on Rehabilitation Robotics, ICORR; 2005; Chicago, Illinois. 2005. p. 25-28.
27. Pernalet, N.; Gottipati, R.; MiMtilineni, S.; Edwards, S.; McCann, E. Eye-Hand Coordination Assessment Using a Robotic Haptic Interface. International Conference on Rehabilitation Robotics, ICORR; 2004; New Orleans, Louisiana. 2004. p. 305-310.
28. Tseng MH, Cermak SA. The influence of ergonomic factors and perceptual-motor abilities on handwriting performance. *Am J Occup Ther* 1993;47:919–926. [PubMed: 8109612]
29. Adi-Japha E, Landau YE, Frenkel L, Teicher M, Gross-Tsur V, Shalev RS. ADHD and dysgraphia: underlying mechanisms. *Cortex* 2007;43:700–709. [PubMed: 17710822]
30. Nimmo-Smith-I W-J. The control of pen pressure in handwriting: A subtle point. *Human movement science* 1991;10:223–246.

Figure 1.
Robot device and pen attachment

Child A- Spontaneous

Child A- Robot

Child B- Spontaneous

Child B- Robot

Child A power spectrum

Child B power spectrum

Figure 2.

Raw data samples from two children: Spontaneous handwriting and writing with a robot

Figure 3. Teacher scores: percent of improvement in children's handwriting with the robot

The black bars indicate the percent of improvement in the participants' handwriting calculated as robot handwriting score minus the spontaneous handwriting score; in some the change was minimal. Most of the children improved their hand writing. In three participants however were rated as having worse handwriting using the robot.

Figure 3. Teacher's and lay ratings: percent of improvement in children's handwriting with the robot

Teacher's scores (white) indicate the percent of improvement in the participants' handwriting calculated as robot handwriting score minus the spontaneous handwriting score. Lay raters (black) compared two handwriting samples with and without the robot and mark the change on a horizontal line; improvement was calculated as the percent of deviation from the center of the line. Most of the children improved their handwriting according to both the lay rater and the teachers; in some the change was minimal. Three different participants however were rated as having worse handwriting using the robot. The lack of agreement could between teachers' scores and lay raters are attributed to the different methods of evaluation and the different in the samples assessed.

Table 1

temporal parameters changes during the different handwriting tasks

1A			mean frequency		coefficient of variation	
	tablet	n	robot off	robot on	p	p
Sentences	digitized	14	2.3 ± 0.4	1.9 ± 0.4	<0.01*	0.8 ± 0.1 0.9 ± 0.1 0.08
	scrolling	14	2.2 ± 0.2	2.0 ± 0.3	0.01*	0.9 ± 0.1 0.9 ± 0.1 0.37
L's	digitized	22	1.8 ± 0.5	1.6 ± 0.4	<0.01*	0.9 ± 0.2 0.9 ± 0.2 0.07
	scrolling	15	1.8 ± 0.4	1.7 ± 0.5	0.01*	1.0 ± 0.2 1.0 ± 0.2 0.1

1B			mean frequency		coefficient of variation	
	robot	n	digitized tablet	scrolling tablet	p	p
Sentences	off	14	2.3 ± 0.4	2.2 ± 0.2	0.26	0.8 ± 0.1 0.9 ± 0.1 <0.01*
	on	14	1.9 ± 0.4	2.0 ± 0.3	0.04*	0.9 ± 0.1 0.9 ± 0.1 0.02*
L's	off	15	1.8 ± 0.5	1.8 ± 0.4	0.14	0.9 ± 0.2 1.0 ± 0.2 0.01*
	on	15	1.6 ± 0.4	1.7 ± 0.5	0.41	0.9 ± 0.2 1.0 ± 0.2 0.06