EVALUATION OF DIFFERENT HANDWRITING TEACHING METHODS BY MEANS OF KINEMATIC ANALYSIS

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ABSTRACT

Development of fine motor skills, especially drawing and handwriting, plays a crucial role in school performance and, more generally, in autonomy of everyday life.
Moreover, a variety of neurological and psychiatric conditions in childhood could stunt the normal motor and cognitive development [1].
In recent years, the analysis of writing movements that allows the characterization of the handwriting process itself, has been directly performed through digital tablets, by measuring parameters extracted from the basic elements of writing, such as components and strokes.
In order to evaluate the handwriting performance in two groups of twenty children each, in which two different teaching methods were used, we examined drawing and handwriting responses acquired by a digital tablet. The dynamic aspects of written traces were studied in five different tasks: a doodle, three graphomotor sequences and a cursive sentence.
Results show differences both in each class along the development and between the two methods.

Index Terms— Handwriting, learning, teaching methods, digital tablets

1. INTRODUCTION

Children spend from 31 to 60% of their school day performing fine motor tasks, in particular handwriting.

The combination of digital tablet and of appropriate algorithms permits to examine both static and dynamic characteristics of writing, providing information for the study of fine motor movements useful for the detection and quantification of both dysgraphia [2] and neurological movement disorders [3].

In this work we studied the handwriting process, using parameters that measure precise kinematic features extracted from digitally recorded writing acquired by means of a commercial tablet [4] in two classes of 2nd grade primary school, following different teaching methods. In particular the factors concerning the basic elements of writing, such as components (representing the writing segment between two successive pen lifts) and strokes (the basic element of writing movements, delimited by the points of minimal curvilinear velocity) were extracted. They have shown to be very promising for hand motor performance quantification [5]. The typical kinematic parameters of hand movements, such as duration, length, mean velocity of strokes (and sometime of the components), have been frequently used for handwriting characterization, providing information on the level of automation and fluency achieved by a student.

This paper represents a preliminary study to evaluate in two samples of Primary Italian students, how different teaching methods could influence these parameters. The influence of the motor control system maturation will also be examined.

2. MATERIALS AND METHODS

2.1. Study population and teaching methods

Each of the two considered samples consisted of about 20 students, Italian mother-tongue, right-handed and without handwriting problems and organic pathologies. In a sample the experimental Terzi's method was used (sample 1); on the contrary, in the other one, the traditional teaching method was applied (sample 2).

In Italian schools, with the spontaneity of the latest teaching approaches, according to the principle "as long as that is readable, it's ok!", the child has to solve, without a lot of support, the main instrumental problems of handwriting (space and direction of movements). With no intervention or external help, the risk is that the student automates more and more possibly painful postural habits and ineffective pen handgrips, as well as bad graphic gestures that may foreshadow cases of dysgraphia, especially when the need of a greater handwriting speed increases in the school activities.

The Terzi's method is a cognitive-motor technique, developed in the first half of the '900 by an Italian teacher, Ida Terzi, to allow blind students to move freely in the great outdoors, thanks to a series of exercises. These exercises act on the organization of the brain, using body movement to arrive at a correct time-space representation in the motor cortex of what the body has made. Over the years, this method, initially created to facilitate the movement of the blind, has also found several other fields of application in rehabilitation or in schools for the study of mathematics and writing [6]. The method improves the perception of both the space around the subject and the time between one movement and another and could represent a valid technique of rehabilitation in cases of head injury or neurodegenerative diseases (like Parkinson's or multiple sclerosis), as well as a useful help for children with learning difficulties.

Writing acquisitions were performed in two specific phases of learning: at the end of first grade of Primary school, when the children had learned the grapheme and at the end of the second grade of Primary, when they had learned the cursive. Before starting the acquisition, written informed consent was obtained from the parents.

2.2. Tasks

In order to study possible parameter dependence either on motor development or on the specific teaching method, all children undertook a series of five exercises: the first four tests, acquired both at the end of the first and the second grade, were totally independent from linguistic aspects, differently to the last one that was acquired only at the end of the second grade, after the cursive learning. The first one (A test) required pupils to draw in fast way, for 7s, a continuous (without pen lifts) doodle in the oblique direction as indicated in Fig.1.

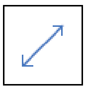

Figure 1: A task.

In the second test (B task), the student had to continue as quickly as possible to the end of the line, the zigzag sequence illustrated in Fig. 2, without pen lifts.

Figure 2: B task.

The third (C task) and the fourth (D task) tests required the student to continue as quickly as possible the illustrated symbol sequence to the end of the line, first in a white space (C task) and then (D task) in a squared line (requiring more accuracy).

Figure 3: C task.

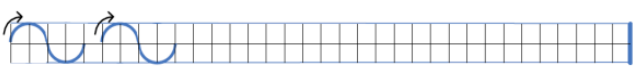

Figure 4: D task.

In the last test (E task), in which adequate linguistic competences were required, pupils were asked to copy in cursive, as fast as possible, the Italian sentence: *In pochi giorni il bruco diventò una bellissima farfalla che svolazzava sui prati in cerca di margherite e qualche quadrifoglio* (meaning "In few days the caterpillar became a beautiful butterfly that fluttered on the grass in search of daisies and some cloverleaf"). This sentence (Fig.5) was constructed in order to contain all the letters of the Italian alphabet.

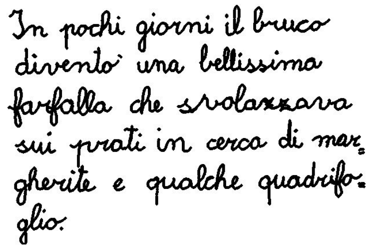

Figure 5: Example of an execution of the E task.

As regard the posture and the prehension to keep, no indication was given to the students.

Data was acquired by means of a commercial digitizing tablet (Wacom, Inc., Vancouver, WA, Model Intuos3), using an ink pen and a sheet of a lined paper, appropriate to the grade attended, in order to reproduce a normal 'pen and paper' context. Pen displacement across the tablet was sampled at 200Hz, both horizontally and vertically, and acquired with a spatial resolution of 5 µm.

2.3. Analysis

Analysis was carried out with a proprietary program written in MATLAB [7]. At first, for each test, the components were identified as the written tracts between two consecutive pen lifts. Then, the horizontal and vertical pen positions were separately filtered by means of a second order low-pass Butterworth filter (10Hz cut-off frequency) with phase compensation and the curvilinear motion characteristics, i.e. position and velocity curves, were derived. To identify the strokes, an automatic segmentation procedure detected points of minimal curvilinear velocity, hypothesizing that each velocity minimum corresponds to a different motor stroke, as claimed by the bell-shaped velocity profile theory [8].

A series of kinematic and static parameters were calculated and analyzed for each task: the total length (mm) and duration (s) of the task; the mean length (mm) and duration of each component (s) and stroke (ms); the mean curvilinear (Vc), horizontal (Vx) and vertical (Vy) velocities (the last two in absolute value) of each stroke (mm/s).

To study possible changes of these characteristic parameters with schooling advances as well as with teaching, at first the mean value of each parameter was calculated in each subject and averaged across students of the same acquisition and school. For each task and parameter, the significance of the difference between the two acquisitions in each school was evaluated by means of the *Wilcoxon* paired-sample test. To evaluate instead the two methods, we compared the two schools, in each acquisition, by means of the *Wilcoxon* rank sum test (or *Mann-Whitney U test*).

3. RESULTS

3.1. Trends with age in the two schools

In the A task, the only fixed time test, children trace a longer length across the age in both samples because of a higher velocity in all directions. As regard the motor planning, in both schools the mean duration of stroke decreases with schooling and also the fragmentation degree (number of stroke normalized on the total numbers of written tracts) is reduced.

In the B test, the whole duration decreases only in the sample 2 although the velocities increase in both samples. This trend can be explained by a greater increment of written path in the sample 1 rather than in the sample 2 (Tab.1). Despite the child makes a written path longer in the second acquisition in both samples, the velocity growth is so strong that even the total duration is reduced. Also in this task the fragmentation decreases with schooling but the mean stroke duration increases, probably because of an increment of their length.

Tests	Sample 1-Terzi's Method			Sample 2-Traditional Method		
	First acquisition	Second acquisition		First acquisition	Second acquisition	
Test: A	mean±1SD	mean±1SD	p-value	mean±1SD	mean±1SD	p-value
Whole length (mm)	279±127	487±148	0.000293	304±140	701±142	6.1e-005
Mean Stroke Duration (ms)	210±40.8	184±55.6	0.0333	192±43.3	149±29.2	0.00671
Mean Curvilinear Velocity (mm/s)	38.8±17.5	69.6±23.9	0.000338	43.5±20.2	98.2±20.1	6.1e-005
Mean Horizontal Velocity (mm/s)	24.8±12.2	44.9±18	0.000517	28.6±14.2	65.2±14.2	6.1e-005
Mean Vertical Velocity (mm/s)	29.6±14.3	53.5±17.2	0.000593	32.6±15.2	73.4±15.1	6.1e-005
#Strokes/#Tracts	1.36±0.941	1.07±0.199	0.02	1.38±0.733	1.02±0.0752	0.0122
Test: B	mean±1SD	mean±1SD	p-value	mean±1SD	mean±1SD	p-value
Whole duration (s)	19.20±2.20	18.63±7.88	0.145	19.99±0.02	14.26±3.93	0.00061
Whole length (mm)	199±54.5	352±44.5	8.86e-005	188±39.2	299±43.4	0.000305
Mean Stroke Duration (ms)	183±25.3	233±28	0.000517	170±10.6	219±29.3	6.1e-005
Mean Curvilinear Velocity (mm/s)	9.7±2.76	17.1±4.34	0.00014	9.12±1.74	18.8±3.01	6.1e-005
Mean Horizontal Velocity (mm/s)	4.39±1.49	6.95±1.87	0.000892	3.83±0.911	9.11±2.46	6.1e-005
Mean Vertical Velocity (mm/s)	7.85±2.41	15±4.03	0.000103	7.55±1.57	15.6±2.29	6.1e-005
#Strokes/#Tracts	4.28±1.68	1.62±0.583	8.86e-005	3.73±1.94	1.8±0.348	0.000427
Test: C	mean±1SD	mean±1SD	p-value	mean±1SD	mean±1SD	p-value
Whole duration (s)	18.91±2.36	13.63±5.58	0.00803	19.11±1.51	11.10±4.69	0.000122
Whole length (mm)	110±28	166±22.2	0.000254	141±20.4	165±31.4	0.00836
Mean pen lift duration (s)	1.51±0.64	0.85±0.23	0.00039	1.23±0.25	0.66±0.21	0.000122
Mean Component Duration (s)	2.01±0.60	1.12±0.40	0.000163	1.80±0.35	0.94±0.32	6.1e-005
Mean Stroke Duration (ms)	154±10.2	170±20.1	0.00359	154±8.5	160±16.4	0.121
Mean Curvilinear Velocity (mm/s)	8.86±2.36	20.7±9.14	8.86e-005	10.8±1.83	24.6±8.57	6.1e-005
Mean Horizontal Velocity (mm/s)	4.82±1.61	11.9±5.82	8.86e-005	5.85±0.974	15.8±5.95	6.1e-005
Mean Vertical Velocity (mm/s)	5.85±1.5	14.1±5.9	0.000103	7.3±1.75	15.8±5.52	6.1e-005
#Strokes/#Tracts	3.03±1.16	1.65±0.568	0.000163	2.83±0.68	1.58±0.348	6.1e-005
Test: D	mean±1SD	mean±1SD	p-value	mean±1SD	mean±1SD	p-value
Whole duration (s)	18.90±1.85	14.51±5.12	0.00376	19.27±1.34	10.76±4.14	6.1e-005
Whole length (mm)	99.8±25.9	142±26.7	0.000625	120±21.6	133±14.5	0.0302
Mean pen lift duration (s)	1.54±0.48	1.02±0.23	0.000967	1.47±0.60	0.82±0.26	0.00116
Mean Component Duration (s)	3.44±1.76	1.62±0.62	0.000132	2.30±1.12	1.39±0.69	0.0151
Mean Stroke Duration (ms)	158±10.4	162±12	0.469	156±10.2	163±11.1	0.107
Mean Curvilinear Velocity (mm/s)	7.06±2.48	15.3±5.6	0.000132	9.1±2.17	19.2±6.45	0.000305
Mean Horizontal Velocity (mm/s)	4.1±1.47	9.12±3.02	0.000132	5.17±1.6	12.5±4.18	6.1e-005
Mean Vertical Velocity (mm/s)	4.24±1.86	9.89±4.66	0.000132	5.72±1.66	11.4±4.23	0.00116
#Strokes/#Tracts	3.26±1.01	2.32±1.04	0.00254	2.35±0.84	1.57±0.55	0.0479

Table 1: Mean±1SD of parameters calculated in all test (except E task, because it was acquired only in the second phase) in the two acquisitions for each sample. The p-values indicate significance of the difference between the two acquisitions in each sample (*Wilcoxon* paired-sample test).

In the C and D tests a similar behavior of the B test was observed as regard the velocities, the fragmentation, the total duration and the stroke duration. The reduction of the total duration is due to the decrease of both mean pen lift duration and mean component (pen down) duration. Unlike of the C test, in the D test children show lower speeds due to the increased accuracy required performing the task.

3.2. Comparison between the two samples in each acquisition

In the first acquisition the parameters analyzed in the two samples do not show significative differences in A and B tests.

Tests	First acquisition			Second acquisition		
	Sample 1	Sample 2		Sample 1	Sample 2	
Test: A	mean±1SD	mean±1SD	p-value	mean±1SD	mean±1SD	p-value
Whole length (mm)	278±124	334±163	0.266	487±148	705±138	0.000302
Mean Stroke Duration (ms)	210±39.8	199±47.3	0.338	184±55.6	148±28.5	0.02
Mean Curvilinear Velocity (mm/s)	38.6±17.1	47.2±22.9	0.254	69.6±23.9	98.7±19.5	0.000878
Mean Horizontal Velocity (mm/s)	24.7±11.9	31.4±16.3	0.19	44.9±18	65.8±13.9	0.00138
Mean Vertical Velocity (mm/s)	29.4±14	35.2±17	0.345	53.5±17.2	73.8±14.7	0.00154
#Strokes/#Tracts	1.35±0.917	1.32±0.676	0.966	1.07±0.199	1.02±0.0728	0.232
Test: B	mean±1SD	mean±1SD	p-value	mean±1SD	mean±1SD	p-value
Whole duration (s)	19.20±2.20	19.99±0.02	0.255	18.63±7.88	14.26±3.93	0.0125
Whole length (mm)	202±54.6	194±41.1	0.642	352±44.5	302±44.5	0.00438
Mean Stroke Duration (ms)	183±24.7	175±18.3	0.121	233±28	219±28.3	0.123
Mean Curvilinear Velocity (mm/s)	9.8±2.73	9.53±2.66	0.899	17.1±4.34	19.3±3.62	0.186
Mean Horizontal Velocity (mm/s)	4.39±1.46	4.1±1.66	0.375	6.95±1.87	9.2±2.41	0.00863
Mean Vertical Velocity (mm/s)	7.97±2.41	7.84±2.09	0.811	15±4.03	16.1±3.05	0.399
#Strokes/#Tracts	4.28±1.63	3.59±1.84	0.0883	1.62±0.583	1.77±0.363	0.101
Test: C	mean±1SD	mean±1SD	p-value	mean±1SD	mean±1SD	p-value
Whole duration (s)	18.91±2.36	19.11±1.51	0.0868	13.63±5.58	11.10±4.69	0.166
Whole length (mm)	110±27.5	141±18.6	5.28e-005	166±22.2	162±32.7	0.535
Mean pen lift duration (ms)	1.51±0.64	1.23±0.25	0.231	0.85±0.23	0.66±0.21	0.0343
Mean Component Duration (ms)	2.01±0.60	1.80±0.35	0.406	1.12±0.40	0.94±0.32	0.0885
Mean Stroke Duration (ms)	153±10.5	154±8.62	0.508	170±20.1	159±16.2	0.0885
Mean Curvilinear Velocity (mm/s)	8.92±2.31	11.3±2.62	0.00424	20.7±9.14	24.5±8.3	0.147
Mean Horizontal Velocity (mm/s)	4.87±1.58	6.27±1.62	0.00714	11.9±5.82	15.9±5.77	0.0228
Mean Vertical Velocity (mm/s)	5.89±1.48	7.55±2.12	0.016	14.1±5.9	15.5±5.47	0.514
#Strokes/#Tracts	2.98±1.15	2.89±0.716	0.978	1.65±0.568	1.6±0.348	0.691
Test: D	mean±1SD	mean±1SD	p-value	mean±1SD	mean±1SD	p-value
Whole duration (s)	18.90±1.85	19.27±1.34	0.602	14.51±5.12	10.76±4.14	0.0196
Whole length (mm)	97.4±26.1	120±20.7	0.00776	142±26.7	132±14.7	0.124
Mean pen lift duration (ms)	1.54±0.48	1.47±0.60	0.155	1.02±0.23	0.82±0.26	0.0179
Mean Component Duration (ms)	3.44±1.76	2.30±1.12	0.00506	1.62±0.62	1.39±0.69	0.159
Mean Stroke Duration (ms)	158±10.3	155±10.2	0.49	162±12	163±10.7	0.778
Mean Curvilinear Velocity (mm/s)	6.95±2.43	9.81±3.01	0.00506	15.3±5.6	19.4±6.3	0.0569
Mean Horizontal Velocity (mm/s)	4.02±1.43	5.68±2.23	0.00844	9.12±3.02	12.8±4.18	0.00848
Mean Vertical Velocity (mm/s)	4.18±1.84	6.19±2.11	0.0027	9.89±4.66	11.5±4.1	0.214
#Strokes/#Tracts	3.32±1.16	2.32±0.772	0.00713	2.32±1.04	1.57±0.533	0.0118
Test: E				mean±1SD	mean±1SD	p-value
Whole duration (s)				208±61	195±40.3	0.787
Whole length (m)				2.85±0.22	2.50±0.35	0.00358
Mean pen lift duration (s)				1.08±0.37	0.63±0.14	4.22e-006
Mean Component Duration (s)				2.56±1.10	1.00±0.44	1.66e-006
Mean Stroke Duration (ms)				181±11	163±9.53	0.00011
Mean Curvilinear Velocity (mm/s)				19.1±4.06	20.7±4.22	0.233
Mean Horizontal Velocity (mm/s)				9.71±2.15	11.3±2.45	0.0885
Mean Vertical Velocity (mm/s)				13.9±3.15	14.6±3.04	0.644
#Strokes				791±284	695±146	0.226

Table 2: Mean±1SD of parameters calculated in all test in the two samples for each acquisition. The p-values indicate significance of the difference between the two samples in each acquisition (*Wilcoxon rank sum test*).

As regard the second acquisition, in the A test, the sample 1 (Terzi's method) has a path length shorter than the sample 2 (Traditional method) because of a lower velocity. In the B test the effect of a lower velocity in the sample 1 is a higher duration of execution that is due also to a longer written path. For these two tests, the fragmentation is the same in the two samples while the stroke duration is higher in the sample 1.

In the C and D tests some differences were found already in the first acquisition: the sample 2 reaches higher speeds than sample 1 thanks to which it is able to draw a greater number of graphemes (longer total path). After the second acquisition, the children of the school which adopted the traditional method (sample 2) are faster than the others, but in this phase both groups write about the same lengths, and then the fastest subjects (sample 2) gain in execution time (reduced total duration, mean pen lift duration and mean component duration). The mean stroke duration and the fragmentation degree (Nr Stroke/Nr tracts) are higher in the test D for the sample 1, where accuracy is required.

The E test, acquired only at the end of second grade, shows that the level of fragmentation does not differ significantly between the two samples. The subjects of the sample 2 have similar velocity values than the others, but the students of the sample 1 write larger letters (longer whole length) in more time.

4. DISCUSSION

From the first comparison between the two acquisitions in each student group is possible to state that both samples made progress between the first and the second learning phase in terms of writing duration, speed and reduction of the degree of fragmentation.

Furthermore kinematic performances are more contained whereas greater accuracy is required.

It is also noted from the results showed in Tab.2 that the sample 1, in which the traditional method was used, is almost always faster than the sample 2. However, performance in terms of writing time and length vary depending on the test. In any case, the students, in which the Terzi's method was adopted, produce a longer written path than the others also in the task E in which they have to write the same number of letters, presumably because the sample 1 would make more readable the written text.

The Terzi's method that wishes prevention from dysgraphia, allows students to produce legible writing since early age school, but at movement speed expense.

In conclusion the kinematic analysis of handwriting is a useful tool to explore graphomotor performance, making possible evaluation of teaching methods as well as of diseases affecting the hand movements and also of the planning of appropriate rehabilitative therapies.

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