Automatic quantification of handwriting characteristics before and after rehabilitation

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Abstract— **Handwriting represents a complex motor behaviour recently analysed by using direct measurements carried out by digitizing tablets. This technology allows objective quantitative kinematic analyses of the quality of writing and can be used to study handwriting disturbances, that can be found in primary school-aged children, as well as the effects of a rehabilitation treatment.**

The aim of this paper is to present a system able to analyse handwriting movements produced by children presenting dysgraphia, submitted to a rehabilitation treatment. The writing task consisted of a sequence of 'lelele', written by the subjects before and after a suitable spatio-temporal rehabilitation treatment (Terzi's method). Handwriting samples from 14 non-proficient handwriters children attending primary school were collected before and after rehabilitation, with the aid of a digitizing tablet (Intuos3®, Watcom). The movements were segmented and each identified stroke was analysed by a suitable ad hoc software that calculated a series of static and kinematic parameters linked to pressure, trajectory and velocity features of the tract, in order to measure the procedure efficacy.

By means of the realized system significant differences in handwriting characteristics estimated before and after treatment were found. In particular a significant increase of the mean pressure calculated on each stroke ($p<0.001$) as well as an increment of the mean velocity during single stroke ($p<0.02$) and the mean width of a stroke ($p<0.02$) were pointed out. Significant differences were also found for the mean velocity along the whole curvilinear written tract ($p<0.02$) between the two conditions. On average the subjects improved in speed of writing after the intervention period thus demonstrating the efficacy of the Terzi's method therapy.

These results demonstrated the potential of the realized system that provides quantitative spatio-temporal measures of handwriting performance, useful for the evaluation and treatment assessment of handwriting difficulties.

Keywords— **Handwriting, Rehabilitation, Terzi's method, spatio-temporal treatment, dysgraphia, kinematic analysis, children.**

I. Introduction

Handwriting represents a specific motor task in which the movement is realized by following a precise spatio-temporal sequence. In this process particular care must be placed both in the correct automation of each grapheme and in the ergonomic aspect of the posture.

Both the main handwriting actions ("inscription" and "progression") require a correct coordination among fine movements and the progression of wrist, forearm and shoulder. The automation of these movements permits the child to became more and more speedy and regular in the tracts execution.

On the other hand, disturbance in the neuromotor efficiency affects pattern velocity and regularity as well as the correctness and legibility of writing [1]. In particular dysgraphia, that represents a learning disability resulting from the difficulty in expressing thoughts in writing, refers to the poor handwriting that can be found in primary school children.

In the last years, the writing analysis has been carried out by using a direct measurement of handwriting movements acquired by digitizing tablets. This technology also allows objective quantitative kinematic analyses of the quality of writing and it has recently been used to characterize the handwriting process in children [1] as well as in elderly subjects [2] and in Parkinson's disease [3].

The aim of this study is to develop an instrument to evaluate a rehabilitation process for graph-motor disorders treatment, starting from handwriting characteristics of primary school children. Parameters linked to the velocity profiles of strokes are used to verify how treatment modifies particular kinematic characteristics. The Terzi's rehabilitation program, a spatio-temporal approach to the treatment of dysgraphia, is in particular examined.

II. Materials and methods

The handwriting of 14 non-proficient handwriters children (aged 9-12 years) attending primary school studies were acquired, before and after a rehabilitation program, at the Dept. of Development Age (ULSS 7) of Pieve di Soligo (TV), by means a digitizing tablet (Wacom, Inc., Vancouver, WA, Model Intuos 2).

Pen displacement across the tablet is recorded at 100Hz sampling frequency both in the horizontal and vertical directions with a spatial resolution of 0.01 mm.

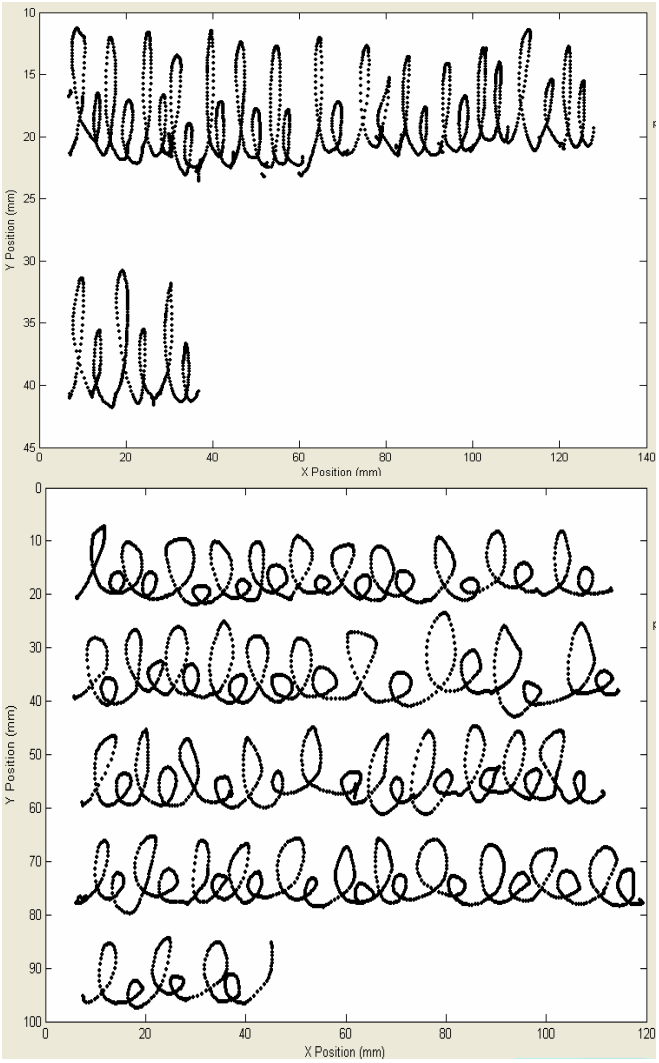

Fig.1 Example of writing test ('lelele') in a child before (top) and after (bottom) the rehabilitation program. In both cases the subject wrote for one minute.

A simple writing exercise mainly involving motor abilities was required. The task consisted of a one-minute continuous sequence of 'lelele'. This pattern represents an almost pure grapho-motor task, not involving significant words, permitting the identification of possible handwriting difficulties.

An user friendly device [4], based on the GUI (Graphical User Interface) tool of MATLAB® (Mathworks), allowing the analysis of handwriting data both in spatial and time domains was used and further developed. In particular it permits the movement segmentation, automatically identifying strokes starting from the curvilinear velocity curve; the curvilinear motion has been reconstructed in the x-y plane starting from the X and Y components. The procedure detects points of minimal curvilinear velocity (Figs. 2 and 3, bottom), hypothesizing that each velocity minimum corresponds to a different motor stroke, as claimed by the bell-shaped velocity profile theory [5]. Stroke identification numbers superimposed on the velocity profiles allow comparison of spatial and temporal elements (see examples in Figs. 2 and 3). A series of static and kinematic parameters linked to pressure, trajectory and velocity features of each stroke are calculated, in order to measure the procedure efficacy and to evaluate what parameters are more sensitive to the recovery process.

The rehabilitation program is a based on a cognitive-motor methodology (Terzi's approach [6]) that permits to develop the ability to obtain aware of the spatio-temporal information reaching cerebral structures from peripherical perception in order to correctly process and integrate them for a conscious use of the body during movement. The treatment affects the organization of both the personal (posture, pen hold) and extra-personal (metrical representation) spaces. In particular a geometrical re-construction of grapho-motor patterns is carried out.

All children undergo the treatment for at least 15 sessions of 45' each, and their handwriting were recorded before and after the conclusion of the rehabilitation program.

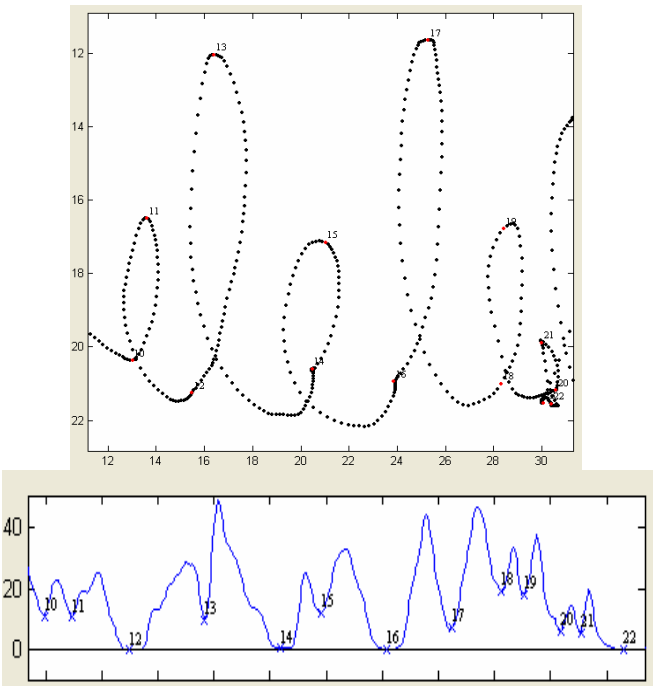

Fig.2 Top: Example of some strokes identification in the writing of Fig.1 (before treatment). The starting point of each stroke is progressively numbered. The horizontal and vertical scales are in mm. Bottom: Curvilinear velocity profile corresponding to the top x-y spatial tract. The numbering is the same of the top panel. Horizontal scale: 1 tick= ½ s; vertical scale in mm/s.

III. Results and discussion

Figure 1 shows the x-y handwriting tests of a child before (top) and after (bottom) the rehabilitation program. Since in both cases the subject wrote for one minute, it is evident that after the treatment the total number of written letters is more than doubled. At the same way also the curvilinear velocity (Figs. 2 and 3) is about doubled.

Moreover, after rehabilitation (Fig.3), the motor planning is different than before (Fig.2) changing from a single letter programming to multiple letter planning. This can be deduced from the instants in which the curvilinear velocity is near zero. More time the velocity is maintained high, more following strokes programming are superimposed demonstrating a higher automation of the motor action.

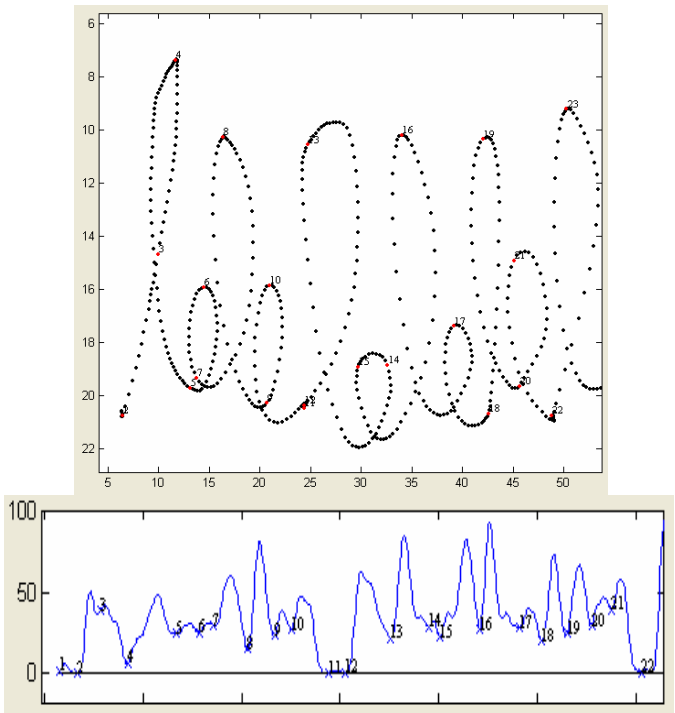

Fig.3 Top: Example of some strokes identification in the writing of Fig.1 (after treatment). The starting point of each stroke is progressively numbered. The horizontal and vertical scales are in mm. Bottom: Corresponding curvilinear velocity profile and stroke numbering. Horizontal scale in sec; vertical scale in mm/s.

By means of the realized system we quantified these modifications founding significant differences in handwriting characteristics estimated before and after treatment. In particular a significant increase of the mean velocity during single stroke ($p<0.02$) and the mean width of a stroke ($p<0.02$) were pointed out (Fig.4). At an individual level, three out of the fourteen children after the treatment showed a little velocity reduction rather than the increment. The increment of the velocity in the stroke production is an index of the old motor program substitution with another more automated that is able to produce a more fluent tract. On the other hand, the velocity decrement present in some subjects is compatible with the hypothesis that these children require a longer time for consolidate the new motor programs, still not at all automated.

Significant differences between the two conditions were also found for the mean velocity along the whole curvilinear written tract ($p<0.02$). On average the subjects improved in speed of writing after the intervention period. Moreover, an increment of the mean pressure calculated on each stroke ($p<0.001$) was generally found (Fig. 5).

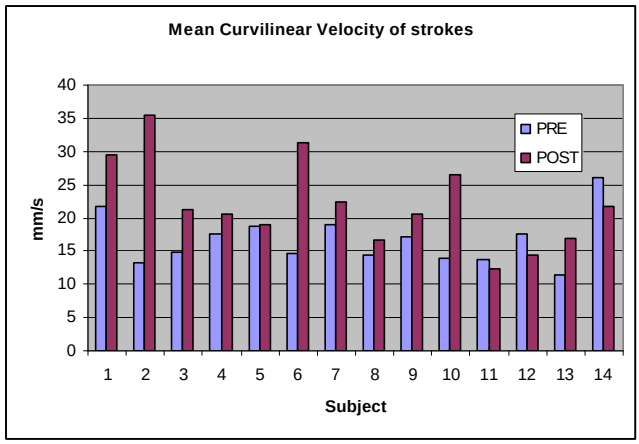

Fig.4 Mean curvilinear velocity of strokes in the considered children before (PRE) and after (POST) the rehabilitation treatment. Generally the velocity significantly increased, in a subject unchanged and in three children decreased.

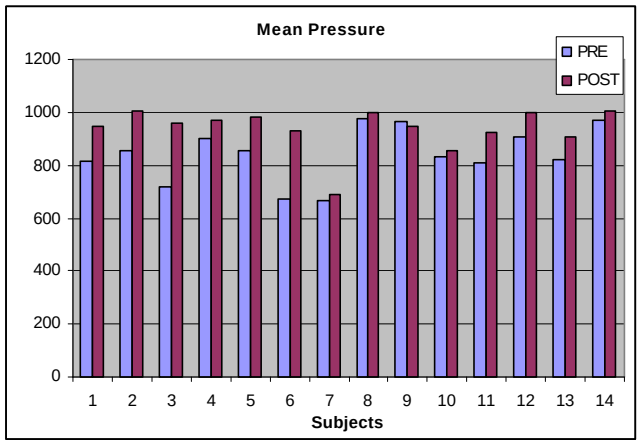

Fig.5 Mean pressure values in the children before (PRE) and after (POST) the rehabilitation treatment. Only in five cases the pressure remains about unchanged.

The pressure increase do not correspond to an excessive muscular tone rather to a passage from a muscular hypotonicity with a fluttering tract to a more checked pressure determining greater accuracy in the production of the graphic tract.

IV. Conclusions

The results, confirming previous preliminary findings [7], demonstrate the potential of the realized system that provides quantitative spatio-temporal measures of handwriting performance, useful for the evaluation and treatment assessment of handwriting difficulties, and can assist for a more comprehensive understanding of handwriting difficulties. The kinematic analysis of handwriting, carried out by the system, not only provides important information about the processes and strategies involved in learning and controlling handwriting but also constitutes a useful support for monitoring progress during the treatment of dysgraphia. In particular, the specific application of the system reported in this study suggests that the application of the Terzi's rehabilitation method improves the graphomotor patterns of the letter especially increasing the stroke speed of children initially identified as having poor handwriting quality.

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