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NUMBER OF ZERO VELOCITY POINTS: A CRITICAL PARAMETER FOR HANDWRITING MODEL ESTIMATION TOWARDS DYSGRAPHIA DIAGNOSIS ASSISTANCE

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Résumé. Une nouvelle voie pour l'analyse de l'écriture manuscrite afin d'aider à diagnostiquer la dysgraphie chez les enfants, en utilisant des modèles oscillatoires dynamiques, a été étudiée. Le *Parsimonious Oscillatory Model of Handwriting* (POMH) s'est avéré capable de reconstruire la trace de l'écriture manuscrite à condition qu'elle soit suffisamment lisse. Pour les enfants souffrant de dysgraphie, POMH conduit à une plus grande déviation lors de la tentative de reconstruction du signal. Cette différence de performance de POMH est censée servir de discriminant pour la détection automatique des enfants dysgraphiques. Un paramètre critique pour POMH est le nombre de points de vitesse nulle dans l'écriture d'un symbole. Les relations entre l'âge, le nombre de points de vitesse nulle et la performance de POMH sont étudiées comme travail préliminaire pour établir un algorithme de classification pour l'aide au diagnostic de la dysgraphie.

Mots-clés. Dysgraphie, Modèle d'écriture, Construction de feature, Classification, Traitement du signal, Morphologie mathématique

Abstract. A new avenue for handwriting analysis to help diagnose dysgraphia in children, using dynamic oscillatory models, has been investigated. The Parsimonious Oscillatory Model of Handwriting (POMH) is shown to be able to reconstruct the handwriting trace provided that it is sufficiently smooth. For children suffering from dysgraphia, POMH leads to greater deviation when trying to reconstruct the signal. This difference in POMH performance is thought to serve as a discriminant for automatically detecting children with dysgraphia. A critical parameter for POMH is the number of zero velocity points when writing a symbol. The relationships between age, number of zero velocity points and performance of POMH are investigated as preliminary work to establish a classification algorithm for dysgraphia diagnosis assistance.

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Keywords. Dysgraphia, Handwriting model, Feature construction, Classification, Signal processing, Mathematical morphology

1 Introduction

Handwriting is crucial for successful integration into society, yet hinges on a long learning process. Handwriting disorders —called dysgraphias— may therefore yield severe consequences spanning from infancy to adulthood. For French children, dysgraphia is usually diagnosed using the BHK test, which consists in copying a text for 5 minutes, with the handwritten production then rated on 13 criteria by psychomotricity specialists (adapted in French by Charles et al. (2004) based on Hamstra-Bletz et al. (1987)). Given the difficulty of an evaluation solely based on visual traces, using tablets to record and exploit the handwriting dynamics has been proposed (Asselborn et al. (2018); Deschamps et al. (2019); Devillaine et al. (2020)), for instance considering the time to make certain strokes to better diagnose dysgraphia.

To better understand and exploit its dynamics, mathematical models of nonpathological handwriting have been proposed, assuming oscillatory and fluid generation of strokes (Hollerbach (1984); André et al. (2014)). The purpose of this work is to study how such models behave when applied to dysgraphic children handwriting, and whether a lack of fit may help diagnosis. To this end, the Parsimonious Oscillatory Model of Handwriting (POMH; André et al. (2014)) and the associated method for parameter estimation are first presented. Then, a first study on the differences in model estimation between diagnosed and non-diagnosed children is presented. A discussion on the future use of our results concludes this work.

2 Parsimonious Oscillatory Model of Handwriting

POMH assumes handwriting results from two orthogonal oscillators, corresponding to different degrees of freedom in hand movements. The model is defined as follows:

$$\begin{cases} \dot{x}(t) = a_x(t) \sin(\omega_x(t) \times t + \phi_x(t)) \\ \dot{y}(t) = a_y(t) \sin(\omega_y(t) \times t + \phi_y(t)) \end{cases}$$

where \dot{x} (resp. \dot{y}) is the velocity on the x -axis (resp. y) and a_x , ω_x and ϕ_x (resp. a_y , ω_y , ϕ_y) are piecewise constant functions. The associated break points of the model $t_{x,1}, \dots, t_{x,N_x}$ correspond to the moments of zero velocity along the x -axis (with the equiva-

lent parametrization for the y -axis), such that for all $i \in \{1, \dots, N_x - 1\}$ and $t \in [t_{x,i}; t_{x,i+1}[$:

$$\omega_x(t) = \frac{\pi}{t_{x,i+1} - t_{x,i}}, \quad \phi_x(t) = -\frac{\pi t_{x,i}}{t_{x,i+1} - t_{x,i}}$$

and

$$a_x(t) = \frac{\pi}{2(t_{x,i+1} - t_{x,i})} \sum_{j|t_j \in [t_{x,i}; t_{x,i+1}[} \frac{x_{j+1} - x_j}{t_{j+1} - t_j}$$

with (t_j, x_j, y_j) the recorded timestamps and coordinates of the pen point from the tablet. The correct estimation of the moments of zero velocity is therefore crucial for the reconstruction of the letters.

3 Number of zero velocity points: a critical parameter for the estimation of POMH

The moments of zero velocity must be obtained from the recorded handwriting data, here comprised of isolated symbols (letter or number). However, the latter are noisy and must be filtered to find a meaningful number of zeros which occurred when the participant wrote the symbol. To do so, the closing morphological operator (acting as a low-pass filter) is applied on a logical variable indicating whether the speed is cancelled for (x_t) and (y_t) discretized signals, respectively.

On the one hand, given that the temporal sampling rate of the tablet is stable ($\simeq 200\text{Hz}$), the size w of the structuring element of the closing operator logically has a direct impact on the number of extracted zero velocity moments, with larger sizes filtering out more zeros. For instance, the first row in Fig. 1 corresponds to a symbol "a" written by a child in second grade (CE1 in the French education system); with w set to 3 (equivalent to a time window of roughly 15ms), 20 zeros are found in x and 26 in y , but with $w = 17$ ($\simeq 85\text{ms}$), the number of zeros respectively drops to 8 and 9. On the other hand, for each symbol, we expect a theoretical fixed number of zeros according to how handwriting is taught in school. However, more zeros do not necessarily mean that the child is dysgraphic, especially for young-aged children who are still in the learning stage. Nevertheless, when children advance through the learning process, the number of zeros should decrease and converge to a fixed number for a given symbol (details in the next section). This tendency is expected by handwriting professionals, even though at the end of the learning process, children usually personalize their handwriting and switch from script to cursive script (attaching letters for flow and efficiency).

Obviously, the more zeros are exploited, the more break points in POMH, and the better the fit to the data. Yet, when imposing a low number of zeros for a given symbol, POMH can successfully reconstruct non-pathological handwriting but has more difficulty with dysgraphic children. For instance on Fig. 1, the panels on the left emphasize the writing process w.r.t time; the child on top row wrote the letter "a" with a single stroke

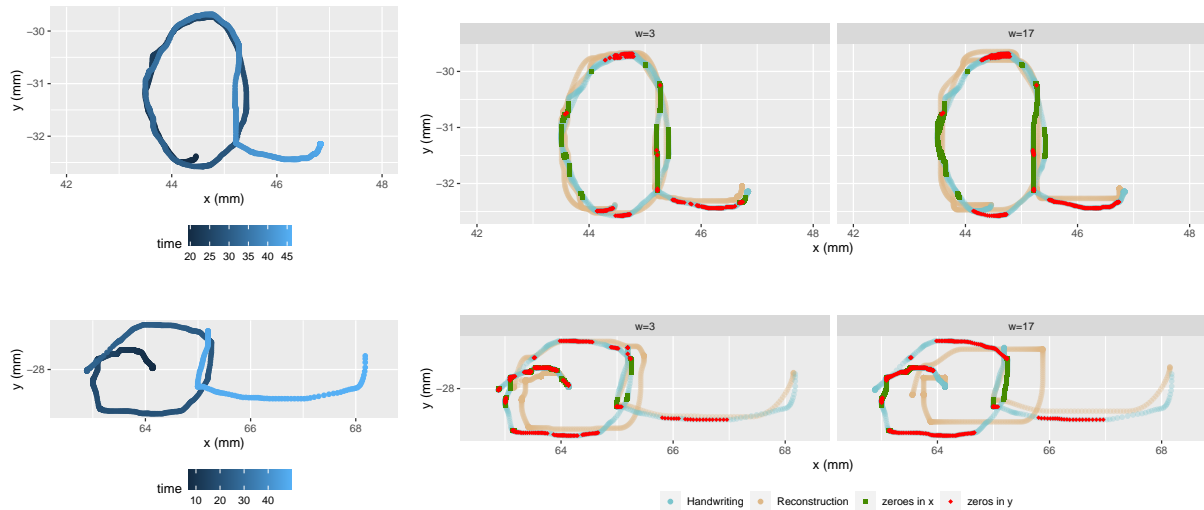


Figure 1: **Letter "a" written by a child in second grade without notable writing trouble (a) and a child diagnosed with dysgraphia (b).** Left: the recorded handwriting where color represents time; Middle (resp. Right): the original signal (light blue), the reconstructed signal (light orange) and moments of zero velocity in x (green square) and in y (red diamond) when the bandwidth of closing operator is $w = 3$ (resp. $w = 17$)

(starting from the bottom, one and a half circle in clockwise direction before drawing the tail), while the (diagnosed) child on bottom row wrote the letter in a more classical way (with two strokes). The other panels overlay the reconstructed trace (light orange) on top of the original trace (light blue), with zeros displayed for both x (green square) and y (red diamond). In the middle panels, with $w = 3$, the numbers of zeros are 20 in x , 26 in y for the first child, 23 and 26 for the second. With $w = 17$ in the right panel, these numbers decrease to 8 and 9 for the first child, 7 and 9 for the second. Although the numbers of zeros are similar given the structuring element size, it can be noticed that the reconstruction with a lower number of zeros moves away drastically from the original trace for the dysgraphic child (Fig. 1 bottom right) and remains correctly estimated for the non-diagnosed child (Fig. 1 top right). The average distance (in millimeters) between the original and reconstructed traces increases from 0.1294 to 0.1509 (+16%) for the non-diagnosed child and from 0.2006 to 0.5006 (+149%) for the dysgraphic child.

4 Number of zeros in x and y decreases when age of participants increases

In this section, we study the relationship between the age of participants and the number of zeros. To study performance at age $a \in [6.5, 12]$ years (first to sixth grade, CP to sixième in the French education system) and consider a sufficient amount of data, children with age $a \pm 3$ months are considered. Then, as we expect the number of zeros to decrease and plateau when size w increases, we simply aggregate across children the number of zeros obtained for different values of w in a wide enough range (in $\{3, 5, \dots, 23\}$) for a given symbol and age range. Numbers of zeros corresponding to the aforementioned plateaus should be over-represented in the resulting distribution. Given that most of the dataset corresponds to non-dysgraphic children, this approach allows to parsimoniously extract the most representative —and possibly meaningful— number of zeros.

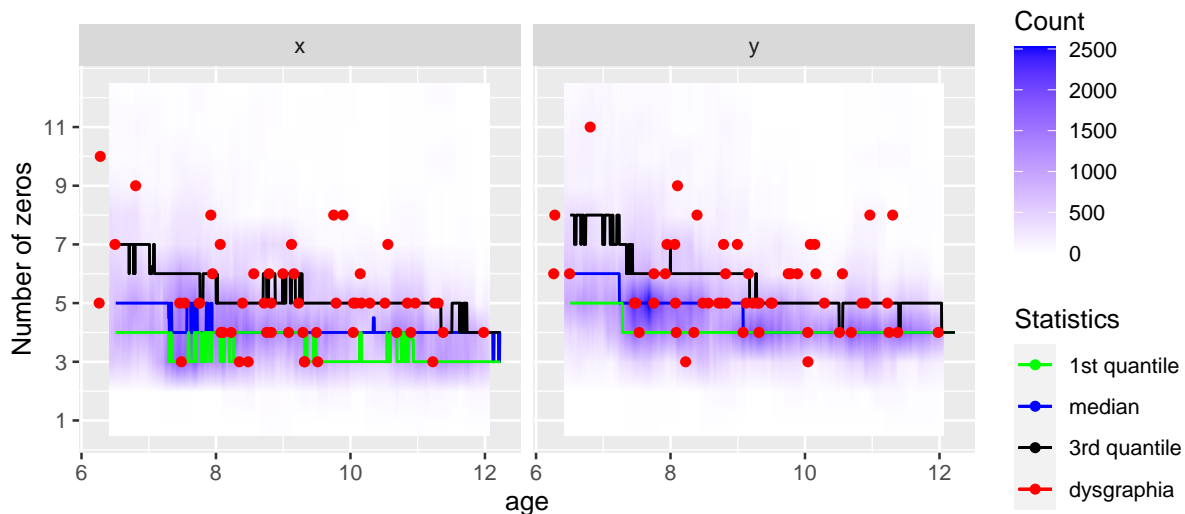


Figure 2: **Density and statistics of the number of zeros on x and y -axis against age, for letter "a"**. For non-diagnosed children, density (blue shade), Q1 (green), median (blue line) and Q3 (black) of the number of zeros in x (left) and in y (right), aggregated across values of w ; For individuals with dysgraphia, median (red points).

If we take the symbol "a" as an example (Fig. 2), the three quartiles for the number of zeros decreases as the age of participants increases. Dispersion also decreases with age, as reflected by the density. Each red point represents the median of the numbers of zeroes (aggregated across sizes w) for each dysgraphic child, when writing letter "a". Compared to non-diagnosed children, it can be observed that there are more red points above the blue line (median for non-diagnosed children) than below. The associated children therefore stop or oscillate more than the average non-diagnosed child of the same age.

5 Discussion

Preliminary results presented in the previous two sections encourage us to develop a classification algorithm for dysgraphia detection based on POMH. Once adequate zero velocity moments are chosen, POMH can reconstruct the handwriting trace for a non-diagnosed participant but deviates from the original signal for individuals diagnosed with dysgraphia (Fig. 1). Therefore, we believe that the reconstruction error made by POMH can help discriminate children with dysgraphia.

The number of zero velocity moments therefore constitutes a critical parameter to exploit POMH reconstruction error, and both depend on the symbol written and age of the participant to classify. For a given symbol in our dataset, we demonstrated that the number of zeros decreases and converges when age increases. One way of including age into the classification algorithm is to adjust the number of zeros as a function of age (e.g., through a regression model).

Once the number of zeros given the symbol and age of the participant is set, the corresponding moments of zero velocity must be determined before applying POMH. We plan to create an inverse function to find the size w from the number of zeros and then apply the mathematical morphology parameterized by w on the recorded handwriting trace to find the moments; or we may try to directly maximize POMH fit by adjusting the positions of the fixed number of zeros (e.g., using dynamic programming).

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