Early Detection of Graphomotor Difficulties through AI-Based Handwriting Analysis: Insights from the Magic Screens and Precious Signs Project

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***Abstract*—Handwriting is an important skill for children's academic development, yet a significant percentage of students experience graphomotor difficulties that can impact their learning, self-esteem, and classroom performance. The *Magic Screens and Precious Signs* project is a longitudinal screening initiative aimed at the early detection of handwriting difficulties in 140 children from the final year of nursery school to the third grade. The project focuses on a digital protocol comprising structured drawing and writing tasks performed on a graphic tablet. This setup is able to capture rich temporal and spatial data during task execution. Artificial Intelligence (AI)-based methods are employed to analyse these features and identify typical versus atypical patterns of graphomotor development. This study demonstrates how combining clinical expertise with AI-driven digital tools can enable early screening and intervention, offering accessible support to educators and clinicians while contributing to inclusive, resilient educational services within smart city ecosystems.**

***Index Terms*—Graphomotor difficulties, Specific Learning Disorders, Dysgraphia, Artificial Intelligence.**

I. Introduction

LEARNING to write is a complex developmental task that plays a crucial role in children's educational success [2]. Handwriting is not only essential for academic tasks such as spelling, reading, and text composition, but it also supports cognitive development and communication skills. However, a substantial number of children encounter difficulties in acquiring effective graphomotor skills, which may reveal early signs of underlying neurodevelopmental conditions, including Specific Learning Disorders (SLD). SLDs are a group of disorders that affect one or more areas of learning, such as reading (dyslexia), writing (dysgraphia), or mathematics (dyscalculia). These conditions are not influenced by intelligence but come from differences in brain functioning that affect how children process information. If not identified early, SLDs can lead to academic struggles, emotional distress, and reduced self-esteem. Early detection is therefore critical to provide timely and tailored interventions. Moreover, early AI-supported screening tools can play a key role in promoting accessible educational services that align with the goals of smart, inclusive, and resilient cities. This can be achieved by embedding such tools within school systems and digital health platforms, enabling continuous monitoring, data sharing, and early intervention in collaboration with educators, clinicians, and urban policymakers. This study addresses this need by developing innovative digital tools and AI-based methods to identify early markers of handwriting difficulties, supporting the broader goal of early SLD screening and prevention.

II. Materials

A. Participants

The *Magic Screens and Precious Signs* project involves a longitudinal study designed to monitor the development of graphomotor skills in early childhood. The participant cohort includes 140 Italian children, recruited during their final year of nursery school (approximately age 5). These children are being observed over three academic years, with assessments scheduled at the end of nursery school, and during the first, second, and third grades of primary school. Before participating in the main protocol, all children underwent preliminary assessments to exclude motor or visual impairments that could confound graphomotor evaluation. The preliminary assessment included the movement ABC-2 test to assess fine motor skills and the bells test, a visual attention task.

B. Protocol and acquisition Tool

Data acquisition takes place using a Wacom One graphic tablet paired with custom software developed for the project. The software records temporal and spatial data during task execution, capturing variables such as pen pressure, spatial coordinates, azimuth, tilt and stroke timing. Each child performs a series of tasks designed by a multidisciplinary team of psychologists, therapists, and educators. Tasks include pre-writing exercises (e.g., tracing lines and shapes), copying letters and words, and free drawing or writing based on age-appropriate prompts. Many tasks included in the proposed protocol were inspired by standardised tests such as VMI [1]. This protocol was carefully designed to balance clinical rigour with child engagement, ensuring reliable data collection in an ecologically valid setting. The resulting digital traces form the basis for feature extraction and AI-based analysis, enabling the identification of typical and atypical graphomotor patterns across developmental stages.

III. Method

The *Magic Screens and Precious Signs* follows a structured methodology designed to study graphomotor development over

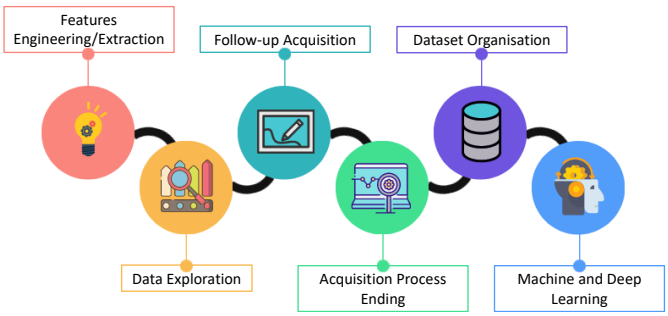

Fig. 1. Proposed method.

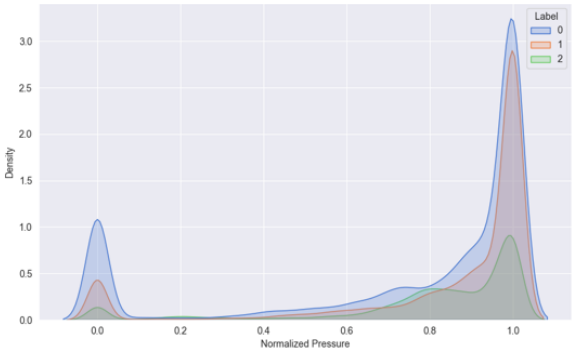

Fig. 2. Kernel Density Estimation (KDE) Plot of Normalised Pressure for Task 13.

time and identify early indicators of handwriting difficulties. The approach combines longitudinal data collection with advanced feature extraction and AI-based analysis. The methodological workflow is illustrated in Figure 1 and described as follows:

- Acquisition Process: Children are individually assessed using a standardised set of writing and drawing tasks on a pressure-sensitive graphics tablet. The tasks are designed to capture a variety of motor and cognitive demands appropriate to their developmental stage. Each session records high-resolution data.
- Follow-Up Acquisition: The same group of children is assessed annually across four time points, at the end of nursery school, and in the first, second, and third grades. This longitudinal design enables tracking of individual developmental trajectories and early detection of persistent or emerging difficulties.
- Feature Engineering and Extraction: Raw signals from the tablet are pre-processed to remove noise and normalise timing and spatial coordinates. A large set of handcrafted and statistical features is then extracted, including spatial, temporal and kinematic and dynamic data, such as speed profiles, jerk metrics, stroke curvature, number of pen lifts, and in-air movement patterns.
- Dataset Organisation: The extracted features are annotated and organised into a structured dataset. Each sample is labelled according to participant ID, session timing, task type, and test scores from collaborating specialists.
- Machine and Deep Learning Analysis: Various machine learning (ML) and deep learning (DL) models will be trained to identify patterns associated with typical and atypical graphomotor development. The aim is to develop classifiers capable of predicting risk levels and differentiating between normal developmental variability and early signs of SLDs, particularly dysgraphia.

The use of longitudinal data allows for tracking individual developmental trajectories and assessing the persistence or resolution of early difficulties, providing a foundation for preventive and personalised interventions.

IV. Preliminary Evaluations

As part of the second-year evaluation in the *Magic Screens and Precious Signs* project, we conducted a preliminary analysis of children's performance in Task 13, where children were asked to write cursive "l" continuously to assess graphomotor fluency and motor planning. Children were grouped into three classes, as determined by expert clinicians based on independent evaluations of their motor and graphomotor development. Label 0 represents children with significant difficulties in task execution, Label 1 includes children showing moderate or borderline performance, and Label 2 corresponds to children demonstrating good competence in performing the task. Figure 2 presents the Kernel Density Estimation (KDE) plot of normalised pen pressure during Task 13. The KDE curves show distinctive patterns across the three groups. Label 2 (green), representing children with good graphomotor control, displays a well-defined and stable pressure distribution. Label 1 (red) shows slightly more variability, while Label 0 (blue), associated with children experiencing difficulties, exhibits a broader and less consistent pressure profile. These results suggest that pen pressure dynamics, as captured by the tablet, may reflect underlying motor control abilities and support early differentiation of graphomotor development profiles.

V. Conclusion

This paper presents the methodology and preliminary findings of the *Magic Screens and Precious Signs* project, a longitudinal study aimed at the early detection of graphomotor difficulties in children. By combining clinical assessments with digital tools, the project enables the systematic monitoring of handwriting development from the final year of nursery school through the early years of primary education. The use of a graphics tablet to collect high-resolution temporal and spatial data during structured handwriting tasks offers a non-invasive approach to capturing detailed information about children's motor control and planning. Preliminary evaluations demonstrate that dynamic handwriting features—such as pen pressure—can effectively distinguish between children with different levels of graphomotor proficiency, as identified by expert clinicians.

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