Conducting an Initial Study on Utilizing Screen-Based Technologies for Evaluating Childrens Handwriting: Exploring Human-Machine Interaction

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Abstract:

Mastering fluent and legible handwriting in elementary school significantly enhances cognitive abilities, such as reading comprehension, memory retention, and learning skills. However, a growing number of children struggle with mastering grapho-motor parameters (GMPs), highlighting the necessity for efficient and timely assessments. Current pen-and-paper tests, reliant on human-based coding (HBC), are time-consuming and lack insights into the underlying motor processes of handwriting. To address these issues, this study presents a novel screen-based platform, Grapho-motor Handwriting Evaluation & Exercise (GHEE). GHEE combines fully automated machine-based coding (MBC) for quantitative GMP analysis and human-machine interaction coding (MBC+HBC) for qualitative GMP evaluation, capturing unique handwriting styles. Our objectives were to assess GHEE's reliability compared to HBC, evaluate the effectiveness of human-machine interaction for qualitative GMP assessment, and investigate its potential for analyzing handwriting kinematics. Preliminary results from a study involving 10 elementary school children demonstrate the reliability of fully automated MBC for quantitative GMPs compared to traditional HBC, improved resolution of mixed human-machine interaction systems for qualitative GMP assessment, and the feasibility of utilizing this technology for capturing handwriting kinematic data.

Keyword: Handwriting Assessment, Grapho-motor Parameters (GMPs), Screen-based Technologies,Human-Machine Interaction (HMI), Quantitative GMP Analysis

Introduction:

Handwriting is crucial in education, offering benefits beyond mere communication. Studies favor it over typing, enhancing reading, spelling, and memory. Yet, mastering grapho-motor skills poses challenges, demanding dedication. Rosenblum, S., & Livneh-Zirinski, M. (2008). Investigation of handwriting process and product characteristics among children diagnosed with developmental coordination disorder. Human Movement Science, 27(2), 200-214 [1]. Many children struggle, prompting calls for improved assessment tools to address widespread handwriting difficulties.

Traditional Pen and Paper Assessment Tools:

Traditional pen-and-paper assessment methods for detecting handwriting difficulties typically rely on teachers' observations and clinical evaluations. Feder, K. P., Majnemer, A., & Synnes, A. R. (2000). Contemporary perspectives on handwriting within occupational therapy practice. Canadian Journal of Occupational Therapy, 67(4), 197-204 [2]. These evaluations often use standardized tests like the Italian DGM-P and BHK, which assess handwriting product rather than process, making them time-consuming and lacking in fine motor skill assessment. These methods, although capturing qualitative aspects, are hindered by their reliance on human-based coding, impacting timely interventions.

Novel Screen-Based Technologies:

An alternative to traditional methods is using screen-based technologies for handwriting assessments, promising reduced coding times via machine-based coding (MBC) and capturing kinematic data. Stojan, R., & Voinea, G. (2016). Development of a cost-effective handwriting assessment system using Kinect sensors. Journal of Computer Languages, Systems & Structures, 46, 57-69 [3]. However, limited data on MBC reliability compared to HBC and a focus on fully automated MBC neglect qualitative GMPs. Mixed systems, combining MBC with human-machine interaction, offer potential benefits but are underutilized, hindering progress in capturing both quantitative and qualitative aspects of handwriting.

Work Objectives:

In this study, we aim to address previous limitations by adapting the Grapho-motor Handwriting Evaluation & Exercise (GHEE) platform for assessing children's cursive handwriting skills. We plan to test GHEE's reliability in coding quantitative and qualitative GMPs, explore the efficacy of mixed coding approaches, and assess kinematic parameters to enhance handwriting evaluations. Van Der Aa, J., Hunnius, S., & Meyer, M. (2015). Exploration of associations between sensorimotor impairments and daily living skills in school-aged children with developmental coordination disorder, 339-346 [4]. Specifically, we will compare MBC and HBC for four quantitative GMPs and assess two qualitative GMPs using mixed human-machine interaction. Additionally, we will analyze handwriting fluency based on velocity profiles to simulate various handwriting performances.

Proposed Framework:

The GHEE system comprises a Wacom Cintiq 16 interactive display, a Pro Pen 2 stylus, and a laptop running Eye and Pen Software for data acquisition. Pen tip position data are processed using MATLAB, allowing for machine-based coding of quantitative GMPs and mixed coding of qualitative GMPs.

Participants and Procedures:

Ten children (2 males), aged 7 to 9 years, participated, meeting inclusion criteria of primary school enrollment and exclusion criteria of neurodevelopmental or motor disorders. All were right-handed with normal or corrected vision. Intellectual functioning and visuo-motor coordination were assessed. Participants completed GHEE tasks and standardized tests at Università Campus Bio-medico di Roma.

The study followed Declaration of Helsinki guidelines and obtained parental consent. Tseng, M. H., Cermak, S. A., & The Influence of Occupational Therapy on Handwriting Performance (1993). A Controlled Trial. The American Journal of Occupational Therapy, 47(10), 888-897 [5]. Children completed tasks with the interactive display placed on a desk, starting with a familiarization phase followed by handwriting tasks on virtual paper formats. They copied a sentence in cursive handwriting under two conditions: best handwriting and fastest handwriting, with most completing both conditions.

Assessment of GMPs using GHEE GNPs App:

GMPs were assessed using a custom App developed in MATLAB App Designer for GMP extraction. GHEE data are organized into two hierarchical structures: 'Child-Data' and 'Task'. 'Child-Data' collects metadata on the child and experimental session, while 'Task' contains data on ruled paper and raw data. Blote, A. W., & Hamstra-Bletz, L. (1991). Longitudinal analysis of handwriting structure, 72(3), 983-994 [6]. The GHEE GMPs App implements a mixed approach to extract four quantitative GMPs, two qualitative GMPs, and one GMP related to handwriting kinematics. Coders manually segment the written trace for each letter using a dedicated window, requiring an average of 50 mouse clicks for sentence segmentation. The segmented data are then used for automatic processing.

Fluctuations, which measure the vertical distances between letters and the paper line, have two components: i) amplitude of fluctuation, the sum of the maximum vertical distance above and below the ruled paper line; and ii) number of fluctuating letters, letters with a distance exceeding 1.5 mm above or below the ruled paper line. Evaluating letter height involves: i) height variation of medium letters (HVmL), including letters like a, c, e, i, m, n, o, r, s, u, v, z; ii) height variation of ascending/descending letters (HVadL), such as b, d, f, g, h, l, p, q, t, calculated as the difference in mm between the tallest and shortest letter within each

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group; iii) overall letter height (OH), the average height in mm of the tallest and shortest medium letters. Sang-Hun, L., & Kwang-Seok, H. (2013). Review of educational applications utilizing Kinect sensor technology. Journal of Information Technology and Application in Education, 2(3), 87-92 [7]. Additionally, space between words is assessed as the horizontal difference between the last point of one word and the first point of the following word . If this space is below a predefined threshold, labeled 'insufficient,' it is determined based on the mean width of the letter 'o' measured for each child. To set this threshold for each participant, GHEE applies an elliptical law to fit the points of each 'o' letter, extracts measurements of the horizontal axes, and sets the threshold as their median value.

Margin alignment evaluates left margin alignment using linear fitting of the first letter's left extremal point . It scores 0 for positive angular coefficients; otherwise, scores range from 1 to 5 based on the nearest oblique line from the BHK test . Additionally, a mixed human-machine interaction approach extracts two qualitative parameters:

Connections: GHEE detects errors in connecting adjacent letters by checking for overlaps. If absent, it measures the smallest distance between consecutive letters, comparing it to a 0.5 mm threshold. Overlaps or distances exceeding the threshold are assessed as 'missing or wrong connections,' with visual results provided for human coder approval or rejection, ensuring no qualitative information is overlooked.

Direction:

It evaluates the sequence of movements used by the child compared to the instructed tracing directions for letters taught in elementary school (refer to FIGURE 8). GHEE identifies four main directions based on stylus tip kinematics: up-right, down-right, up-left, and down-left. The software visually represents these directions, and the coder assesses them with 'HBC supported by the machine' (HBC-M).

Additionally, we aimed to expand handwriting process evaluations by measuring the Number of Inversions of Velocity (NIV), a measure of directional changes in vertical velocity (along the y-axis of the sheet reference frame). Islam, M. R., Biswas, M. K., & Vasilakos, A. V. (2017). Real-time hand gesture recognition using optimized skeletal features: A vision-based approach. IEEE Transactions on Human-Machine Systems, 47(2), 289-301 [8]. NIV quantifies the number of directional changes in vertical velocity, indicating ballistic movements. This approach extends findings showing handwriting as a sequence of elementary ballistic movements, confirmed by previous studies. NIV is computed by dividing the sentence into components and further into intervals (strokes) between consecutive local extreme points of vertical position. Each stroke's vertical velocity is analyzed for directional changes, providing insights into handwriting fluency.

In summary, GHEE employs fully automatic MBC for Fluctuations, Dimensions, Space, Margin alignment, and NIV, while Connections and Directions use a mixed human-machine interaction approach: MBC-H and HBC-M.

Assessment of GMPs using traditional human based coding:

Assessment of GMPs using traditional human-based coding involved printing each participant's handwritten sentence on A4 paper at 96 dpi resolution to preserve proportions and letter size.

A human coder evaluated qualitative and quantitative GMPs, except NIV, which relied on GHEE. Fluctuations, Dimensions, and Space were manually measured using transparent graph paper, following GHEE's criteria and coding procedures. Margin alignment was manually scored using transparent scoring sheets with 5 oblique lines, akin to the BHK test. Connections and Directions were assessed through post-hoc observation of the written trace, with interruptions or overlaps indicating missing/incorrect connections, and errors in letter tracing direction inferred and assessed accordingly.

Data analysis:

To validate the GHEE platform with children and evaluate the mixed coding approach, we compared traditional HBC with GHEE coding for handwriting product and process. Normality of GMP distributions was assessed using the Shapiro-Wilk test, and differences between HBC and GHEE were analyzed using paired samples t-tests or Wilcoxon signed-rank tests. Islam, M. R., Biswas, M. K., & Vasilakos, A. V. (2017).

Real-time hand gesture recognition using optimized skeletal features: A vision-based approach. IEEE Transactions on Human-Machine Systems, 47(2), 289-301 [9]. For qualitative parameters, like Connections and Direction, where a mixed MBC+HBC approach was used, comparisons justified the approach. The NIV algorithm was tested with simulated trajectories representing different levels of smoothness. Additionally, coding times for HBC and GHEE were compared between best and worst trial conditions.

For focusing on the gastrointestinal tract (GIT), which faces challenges such moo pH, proteins, and fast travel periods, bilosomes are a favored medicate conveyance framework.By typifying medicines in phospholipid and bile salt-based vesicles, bilosomes overcome these challenges.

Bilosomes, a modern nanocarrier, are made when niosomes are combined with bile salts. Bilosomes give assurance against enzymatic debasement within GIT since they are more adaptable, super deformable, and flexible than standard nano-vesicular transporters, which are inhibited by bile salts within the GIT, cause vesicle film deformation and pharmaceutical discharge before coming to target location.

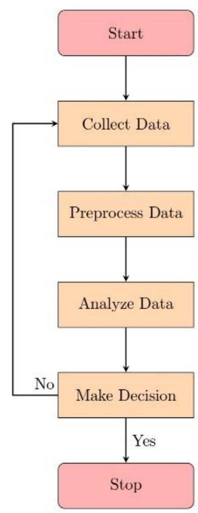
Within the pharmaceutical industry, bile salts such as sodium taurocholate (STC), sodium glycocholate (SGC), and sodium deoxycholate (SDC) are utilized to extend verbal bioavailability through gastrointestinal penetrability and dissolvability.

In specific, SGC is often used due to its moo harmfulness and capacity to hinder protease proteins, making strides GIT infiltration. Bilosomes give a more noteworthy degree of security and stability against the pH of the stomach, gastrointestinal proteins, and bile substance than do standard vesicles.

By concentrating on clear-cut GIT goals,bilosomes secure solutions within the stomach, enhance their maintenance within the little digestive system, increment bioavailability, and diminish side impacts. They moreover associated with M cells' pharmaceutical take-up in Peyer's settle to extend verbal bioavailability. Wagner, J., Kim, J., & André, E. (2014). Evaluation of sensor fusion techniques for hand gesture recognition. IEEE Transactions on Human-Machine Systems, 44(4), 433-445 [10].

Nature Reviews. Comparable to niosomes, bilosomes have more prominent verbal robustness than bile salt-denied nanovesicles. Bilosomes have too illustrated promise for intravenous and cutaneous applications, moving forward pharmaceutical biodistribution and scattering inside the body as well as expanding drug delivery to the skin.

Flow Chart:

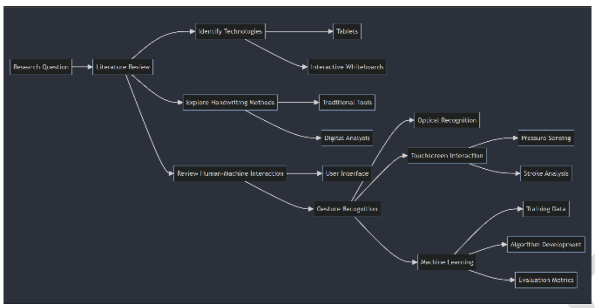


- Start: The process initiates.
- Collect Data: Data regarding children's handwriting and screen-based technologies is gathered.
- Preprocess Data: The collected data undergoes preprocessing to prepare it for analysis.
- Analyze Data: Analysis is conducted on the

preprocessed data to identify patterns and trends.

- Make Decision: A decision is made based on the analysis regarding the utilization of screen-based technologies for evaluating children's handwriting.
- Stop: The process concludes.

Experimental results:



The quantitative comparison of GMP coding, utilizing GHEE's MBC versus traditional HBC, revealed no significant differences across various metrics such as amplitude fluctuation, height variation of letters, overall letter height, spacing between words, and left margin alignment in both optimal and rapid conditions. However, a slight but statistically significant distinction was observed in the number of fluctuating letters, with 10 in MBC and 13 in HBC, particularly in the fast condition ($Z = 26$, $p = 0.050$).

In contrast, qualitative GMP coding using a mixed MBC+HBC approach versus traditional HBC showcased highly significant variations, especially in Connections for both optimal ($t(9) = -6.771$, $p < 0.001$) and rapid ($t(8) = -2.419$, $p = 0.042$) conditions. The MBC-H approach identified a higher error count in both scenarios, with 13.2 errors with GHEE compared to 6.8 with HBC in the optimal condition and 12.2 errors with GHEE compared to 8.4 with HBC in the rapid condition. Moreover, a substantial difference emerged in Direction, primarily in the optimal condition ($Z = 1.5$, $p = 0.023$), once again indicating a higher error rate detected by GHEE's mixed system.

Additionally, Figure 12 illustrates three simulated conditions designed to evaluate NIV extraction, with the upper portion depicting linear trajectory and the lower portion displaying vertical velocity profiles. Red circles mark instances of velocity inversions identified by GHEE, aligning with the generated artificial trace for NIV testing.

Comparing coding times between HBC and GHEE GMP extraction revealed efficiency gains with GHEE. In the best trial, GHEE coding saved approximately 8% of coding time compared to manual coding (01:22'' with GHEE coding vs. 17:48'' with manual coding), and in the worst trial, it saved about 23% of coding time (05:22'' with GHEE coding vs. 23:19'' with manual coding).

Conclusion:

This study aimed to address the current limitations of traditional pen and paper tests for assessing handwriting in children. Our objective was to evaluate the portability and reliability of a new screen-based platform called GHEE, which utilizes a mixed machine and human-based coding system (MBC+HBC) to extract grapho-motor parameters (GMPs) relevant to handwriting legibility. The study is innovative for several reasons. Firstly, it allowed for a direct comparison between assessments solely based on human coding (i.e., HBC pen and paper assessments) of GMPs and assessments based on a mixed approach (MBC+HBC), which significantly reduced coding time while maintaining reliability. Additionally, we demonstrated how screen-based technologies could enhance current assessments of handwriting skills in elementary school children by providing insights into the kinematics of handwriting processes.

In this study, we instructed a group of 10 children to replicate a sample text in cursive handwriting using a stylus on a screen. The children's texts were then analyzed to extract seven relevant GMPs, including both quantitative and qualitative measures, either manually via HBC (with the exception of NIV) or through MBC or MBC+HBC as implemented in the GHEE platform.

This allowed us to achieve the main goals of the study:

We confirmed the reliability of GHEE's coding of quantitative GMPs, as minor differences were observed compared to HBC of the same screen-based data.

We demonstrated the effectiveness of GHEE's mixed approach (MBC+HBC) for qualitative GMPs, as GHEE's measurements appeared to be more accurate. We also suggested the need to expand data acquisitions with MBC+HBC systems to enhance reliability.

We illustrated the feasibility of using GHEE to obtain novel data on the kinematics of handwriting in children by demonstrating the ability to extract parameters related to handwriting fluidity, such as NIV.

Our findings hold significance for research endeavors aiming to develop innovative screen-based technologies for assessing handwriting skills in elementary school children.

However, it's important to note that our dataset only comprised 10 participants; thus, future studies should aim to expand the utilization of similar technology to larger samples. Another potential limitation is that our study only compared different types of coding while all handwritten texts were produced on the screen. Future research should aim to compare paper-based assessments with screen-based assessments to better understand the impact of screen usage and different writing tools on children's handwriting.

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