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Handwriting Skills and Their Role in Text Generation: A Longitudinal Study with Graphonomic Measures

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Abstract: This study sought to examine the influence of transcription skills, evaluated using graphonomic measures, on the proficiency of text generation in students attending primary schools in Spain. A longitudinal design was employed involving 278 Spanish students distributed across three cohorts (cohort 1: 1st-2nd-4th grade; cohort 2: 2nd-3rd-5th grade; and cohort 3: 3rd-4th-6th grade). Two data collection points were used to administer the graphonomic measures, and a composition letter task was conducted at the conclusion of the study. Four multigroup structural equation models were employed, examining the direct pathways from graphonomic measures (i.e., pressure, speed, pauses, and road length) on text generation (i.e., length, fluency, planning, revision, and organization). The models demonstrated a good fit to the data. The findings from the four models, analyzed within the three cohorts, indicated that the significant effect of transcription (i.e., handwriting) on text production was primarily observed in Cohort 1 (early grades), while no significant effects were found in Cohort 2 (intermediate grades). This suggests that the importance of handwriting in text production in a transparent orthography may be more pronounced during the initial stages of writing development when students are acquiring foundational writing skills.

Keywords: *Graphonomic measures, longitudinal structural equation modeling, text generation, transcription skills.*

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Introduction

Handwriting skills are essential for academic success and develop over several years (Coradinho et al., 2023). In its early stages, handwriting demands conscious attentional control, but with consistent practice, it evolves into an automated process. As handwriting automation is established, cognitive resources are freed, allowing for their redirection toward higher-order cognitive functions such as idea generation and vocabulary selection. (Berninger & Swanson, 1994; Medwell & Wray, 2007).

There are two models of writing that have received significant conceptual support: the "simple view of writing" model (SVW) (Juel, 1988; Juel et al., 1986) and the "not-so-simple view of writing" model (NSVW) (Berninger & Amtmann, 2003; Berninger & Winn, 2006). According to the SVW model, writing is a product of two skills: transcription and ideation (also known as text generation) (Berninger et al., 2002; Juel et al., 1986). A revision of this model was suggested, which expanded upon the simple view of writing in two significant ways (Kim & Schatschneider, 2017). Firstly, it incorporated executive function and self-regulatory processes (such as attention, goal setting, revision, etc.), in addition to text generation and transcription skills (Berninger & Amtmann, 2003; Berninger & Winn, 2006). Secondly, it positioned working memory (WM) as the central regulatory component for these three elements (text generation, transcription, and self-regulation), which necessitate access to long-term memory during the planning and composing phase and short-term memory during the revision process (Berninger & Winn, 2006). Therefore, in this new model, transcription skills (i.e., handwriting fluency and spelling) and executive self-regulatory functions (i.e., attention and memory) work together for text generation. Text generation encompasses both the generation of ideas and the translation of these ideas into linguistic expressions, which are intricately linked to oral language skills.

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Literature Review

Transcription Skills (Handwriting) and Text Generation

Proficiency in handwriting is typically characterized with respect to both readability and speed (Graham & Weintraub, 1996). An increasingly substantial body of research now suggests that handwriting plays a crucial role in facilitating the generation of creative and effectively structured written content, influencing not only fluency but also the overall quality of composition (Berninger & Swanson, 1994; Graham et al., 1997). In English-speaking children, Graham et al. (1997) recorded standardized path coefficients ranging from .5 to .7, linking handwriting fluency with both composition quality and composition fluency. These connections were observed within significant cohorts of students spanning from first to third grade. Abbott et al. (2010) found that the longitudinal path from handwriting to written composition was significant only from Grades 3 to 4 and was of small size (.14). In first grade, Wagner et al. (2011) found that handwriting fluency had a significant and moderate correlation with three out of the four factors of written composition, namely macro-organization, productivity, and complexity, as well as spelling and punctuation, with the strongest relation found for productivity (i.e., number and diversity of words used). Complementary to these studies, Limpo and Alves (2013) employed structural equation models in a longitudinal design involving two measurement points and two cohorts (4th-6th and 7th-9th grades) with Portuguese students. Their research focused on examining the relationship between transcription skills, planning, revising, self-efficacy, and writing quality. The findings indicated that in the younger cohort, transcription skills accounted for 76% of the variance and directly influenced the quality of written compositions. In the second cohort, the effect was indirect and mediated by planning and self-efficacy. This suggests that Portuguese students in the developmental stage (4th-6th grade) still experience direct effects of transcription skills on textual production.

Alphabetic writing systems manifest substantial disparities in the extent of regularity evident in grapheme-phoneme correspondences (GPC, used to read) and phoneme-grapheme correspondences (PGC, used to spell). Spanish, for instance, has a transparent and fine-grained orthography (Jiménez et al., 2009). The majority of the aforementioned studies have been carried out in languages with opaque orthography. In contrast, few studies conducted in languages with highly shallow orthographies, such as Turkish and Finnish, have demonstrated that the impact of transcription skills, particularly handwriting, diminishes beyond 1st grade in relation to writing production (Babayigit & Stainthorp, 2011; Lerkkanen et al., 2004). In the Spanish language, there is limited research exploring the role of transcription skills in writing production and quality (e.g., Jiménez & Hernández-Cabrera, 2019). Overall, none of these studies analyzed handwriting using graphonomic measures.

Evaluation of Writing Based on Real-Time Measures

An established scholarly viewpoint asserts that comprehending the evolution of writing skills is most effectively achieved by adopting a process-oriented framework, as articulated by Berninger et al. (1996). As suggested by Wicki et al. (2014), many studies on fluency have relied on handwriting speed, measured by the number of letters a person can write when copying or composing a text within a given amount of time. However, handwriting fluency entails more than speed; it involves the automaticity of the writing movements. Fluent and legible movements have been identified as manifestations of automation, assumed to be important for saving cognitive resources for higher-order writing tasks, such as lexical or syntactical aspects (Bourdin & Fayol, 1994; Germano & Capellini, 2019; Graham et al., 2000). In the field of graphonomic research, handwriting is conceptualized as a dynamic process that integrates spatial and kinematic parameters intrinsic to the act of writing. These parameters intricately link to an individual's proficiency in handwriting (Alamargot et al., 2006; Tucha et al., 2008). The nuanced understanding of handwriting fluency, emphasizing processes, has significantly advanced through the application of graphonomic research methodologies. These involve meticulously recording kinematic data, specifically related to handwriting movements, using digitizing tablets and computational programs (Meulenbroek & Van Galen, 1986), and incorporating real-time measures of writing (Alamargot et al., 2007). Referred to as graphonomic metrics, these encompass documenting parameters, including pressure, speed, road length, and pauses during writing. This data collection is facilitated through the use of digital tools like tablets, computers, and specialized software (e.g., Eye and Pen2, Alamargot et al., 2006; Ductus; Guinet & Kandel, 2010). Pressure is defined as the force exerted by the pen tip during strokes. Speed is the average velocity, considering all pen contact points with the tablet surface. The duration of pauses represents the period during which the pen did not maintain contact with the tablet surface, encompassing both pauses above and below. Road length refers to the distance covered on the tablet surface within a specific duration, excluding the time spent in pauses. Assumptions indicate that greater speed, lower pressure, and shorter distances in handwriting are linked to cognitive resource savings (Bourdin & Fayol, 1994). However, a notable gap exists in literature regarding the use of technology to measure handwriting metrics, especially among early literacy students.

Overview of the Current Study

As highlighted by Wicki et al. (2014), "there's a recognized research gap concerning the impact of handwriting automaticity on higher-order writing processes like ideation and syntactic structure monitoring" (p. 88). To our knowledge, there are no Spanish studies that employ computerized evaluations through digital surfaces (tablets) specifically aimed at analyzing the role of handwriting automation in text generation. In contrast to previous studies that utilized structural equation models and product-based measures of writing (e.g., Abbott et al., 2010; Graham et al., 1997; Jiménez & Hernández-Cabrera, 2019; Limpo & Alves, 2013; Limpo et al., 2017), the present research examined the developmental changes in transcription skills (i.e., handwriting) through the recording and analysis of graphonomic measures. Longitudinal multigroup structural equation models were utilized to examine the associations between transcription (namely, handwriting) and its impact on both the generation and quality of textual production within the context of a transparent orthography.

Research Models and Hypotheses

Four models were proposed to test the study's hypotheses. The observed indicators (manifest variables) encompassed tasks such as writing the alphabet from memory, cursive alphabet copying, and allograph selection. The cohort variable was used for grouping, while the exogenous latent variables included pressure, speed, pauses, and road length at the initial measurement time point. Handwriting pressure, speed, pauses, and road length at the subsequent measurement time point served as first-order endogenous variables. It is assumed that the graphonomic skills represented by the latent factor maintain relative stability over time. In according to this model, the shared variance among the observable indicators can be attributed to the influence of exogenous latent variables measured at different time points, which directly impact endogenous variables (e.g., writing length, fluency, planning, revision, and organization of the text) at the third measurement time point. Studies conducted in transparent orthographies, which have utilized product-based measures, have shown a diminishing impact of transcription skills, particularly handwriting, on writing production beyond the 1st grade (Babayigit & Stainthorp, 2011; Lerkkanen et al., 2004). In the present study, graphonomic measures are employed, providing real-time analysis of stroke movement. In this regard, we sought to determine whether the same scenario would emerge regarding the role of handwriting fluency in text production.

Methodology

Participants

A sample of 322 children between the ages of 6 and 9, encompassing both genders and grades 1st to 3rd, was carefully selected for this study. The sample size was determined based on the specific school and grade levels. More precisely, we intentionally selected individuals from a region situated on the island of Tenerife, which is part of the autonomous community of the Canary Islands, Spain. Initially, the study involved a total of 322 students ranging from 1st to 3rd grade. However, the final longitudinal sample consisted of 278 students. The sampled students come from various socio-economic backgrounds and were divided into three distinct cohorts. Cohort one was recruited during their 1st grade (n = 105; 58 boys, 47 girls) and followed through their 2nd and 4th grades. The average age at the beginning of the study was 81.8 months (SD = 3.50 months), with an age range of 78.3 to 85.3 months. Cohort two was recruited during their 2nd grade (n = 110; 55 boys, 55 girls) and observed until their 3rd and 5th grades. The average age at the initiation of the study within this cohort was 92.4 months (SD = 6.09 months), ranging from 86.31 to 98.49 months. Last, cohort three was recruited during their 3rd grade (n = 107; 58 boys, 49 girls) and monitored until their 4th and 6th grades. The average age at the outset of the study for this cohort was 105.1 months (SD = 3.64 months), with an age range of 101.5 to 108.7 months. Statistical analysis revealed no significant differences in gender distribution among the cohorts, as evidenced by $\chi 2$ (2) =.67, p =.71. Exclusion criteria were implemented based on the presence of intellectual, sensory, physical, mental, or motor impairments, as ascertained from the Specific Educational Support Needs report obtained from the educational institution.

Instruments

Early Grade Writing Assessment (EGWA) (Jiménez, 2017): The EGWA-K is a standardized test designed to assess writing skills in primary education grades. It comprises 10 tasks of varying difficulty levels, spanning from simple letter copying to composing a story. It was developed as part of a large-scale project supported by UNESCO. The results indicated the reliability of EGWA measures. For the internal reliability of specific EGWA tasks, Cronbach's alpha coefficients were 0.76, 0.90, 0.70, 0.71, 0.71, and 0.72 for word copying, sentence copying, writing dictated words with inconsistent spelling, writing words following spelling rules, writing pseudowords, and writing sentences from dictation, respectively. Overall, the interrater reliability of the EGWA ranged from high to very high. Positive and significant correlations were observed between EGWA and the Standardized Test for the Initial Assessment of Keyboard Writing (TEVET, by its Spanish acronym), indicating a strong relationship between the scores of the two tests.

Software Eye and Pen 2 (Alamargot et al., 2006): This software was used for the recording of real-time graphonomic measurements pertaining to the writing process. Three tasks from the original EGWA were adapted for use with Eye and Pen 2: writing the alphabet in order from memory, alphabet copying in cursive or manuscript, and allograph selection. The EGWA tasks were adapted by programming scripts in the Eye and Pen 2 software, allowing for the measurement of various graphonomic variables: a) Pressure was quantified in hertz (Hz) as the mean pressure level (force) applied by the pen tip across all strokes executed by the participant within a one-minute interval; b) speed is defined as the average velocity achieved by the child during the first minute of the task, measured in centimeters per second, and takes into account all pen contact points with the tablet surface; c) the duration of pauses was measured in milliseconds, computed as the period during which the pen did not maintain contact with the tablet surface (including both pauses above and below) within the span of one minute.; and d) road length (expressed in centimeters) within a specific duration (expressed in milliseconds), excluding the time spent on pauses.

Composition Letter (adapted from Berninger et al., 1996): This instrument was used to assess text generation. It specifically focused on capturing objective aspects of writing, including aspects such as the length and content characteristics of the composition letter. To comprehensively assess the various stages of letter composition, namely revision, planning, and organization, we utilized the Coding Scheme of the Cognitive Processes of Writing (Whitaker et al., 1994). In addition, we used the Written Composition Revision Instrument (IRCE) (Arias-Gundín & García-Sánchez, 2006) to analyze participants' understanding of the revision phase processes. The instrument's reliability was rigorously assessed using Cronbach's alpha, yielding a coefficient of .90, indicating a high level of internal consistency. Regarding the quantitative aspects of writing, we determined writing length by aggregating the word count produced at the 5 and 10-minute interval. Writing fluency was calculated based on the cumulative count of correctly written words within the same time intervals (5 and 10 minutes)."

Procedure

During the 1st and 2nd measurement moments, the EGWA assignments were administered collectively to groups of five students using the digital format of Eye and Pen 2. A specially conditioned classroom was utilized to isolate sound and distribute the necessary equipment. This included notebooks (Acer One 722, 10.1"), digital tablets (Wacom Intuos-4), and pens (Intuos Inking pen). Each participant was provided with the opportunity to access the instructions presented on the notebook screen and then proceed to transcribe the graphemes onto a sheet of lined paper, following the prescribed Montessori writing pattern. The lined paper was positioned over the digitizer tablet (Wacom Intuos-4) and was replaced after each task undertaken by the student. Handwriting was conducted using an Intuos Inking pen (KP1302). Each digitizer tablet had distinct parameters configured for the beginning and ending zones, which needed to be activated by the tip of the Inking pen at the start and end of each task. A complete session typically lasted around 15 minutes. For the 3rd measurement moment, the participants completed the free writing of a letter task (adapted from Berninger et al., 1996). This task was administered collectively in the classrooms using the pen and paper modality. The assignment consisted of four phases: a) preparation of the planning of the letter; b) preparation of a rough draft of the letter; c) preparation of a final draft of the letter; and d) revision of the text using the IRCE scale (Arias-Gundín & García-Sánchez, 2006). The entire session for this measurement moment lasted 45 minutes.

Data Analyses

In our study, structural equation modeling (SEM) was employed as the statistical technique. To ensure the robustness of our findings, we carefully considered several assumptions as normality of residuals, homoscedasticity, linearity, independence of errors, and absence of multicollinearity. The study employed a multigroup approach in the structural equation models to evaluate four structural models. The aim was to examine whether the effect of graphonomic measures on the production and quality of writing varied across different measurement moments. The fit of the models was analyzed under two conditions: comparing the covariance and path diagrams between the latent factors to determine if they were equal at each level of development and observing if the parameters varied at each level of development. The analysis of structural equations was conducted using the Lavaan package (version 0.5-16) in R Core Team (2013).

The analysis of the results for each model involved several steps: testing if all four models fit the data (baseline model); assessing whether each model aligned with the data within each cohort, without imposing any constraints on the parameters (configural model); checking if the path coefficients between latent variables and observable indicators were equal, resulting in equal factor loadings between cohorts (measurement model); verifying if the loading (measure) and regression (structural) parameters were the same for all cohorts by setting them to be equal; and testing the invariance of each model across different cohorts.

To evaluate the model fit and follow Bentler's (2007) conventions, the chi-square statistic and the comparative fit index (CFI) were used to test the invariance across cohorts. Additional goodness-of-fit index, such as the root mean square error of approximation (RMSEA) and standardized root mean square residual (SRMR), were also employed. Prior to evaluating the model, the latent variables were expanded by setting the restrictions on load unit (Bollen, 2014). The nonstandardized coefficients of the observed indicators for the latent variables in all four models were fixed at 1.0.

Findings/Results

Table 1 shows descriptive statistics by cohort and measurement time point for the graphonomic variables of pressure, pauses, speed, and road length. Table 2 shows descriptive statistics by cohort for the variables of length, fluency, planning, revision, and organization in the Composition Letter task.

Table 1. Descriptive Statistics by Cohort and Measurement Time Point for the Graphonomic Variables: Pressure, Pauses, Speed, and Road Length

	Cohort 1 (1-2-4 grade)				Cohort 2 (2-3-5 grade)				Cohort 3 (3-4-6 grade)			
Task	**M**	**DT**	**As**	**κ**	**M**	**DT**	**As**	**κ**	**M**	**DT**	**As**	**κ**
Pressure												
Alphabet writing$_1$	59.43	33.36	1.80	4.56	31.65	17.71	1.47	3.64	25.92	13.06	2.25	8.15
Alphabet cursive copy$_1$	67.32	32.77	1.35	2.85	51.68	30.68	2.27	8.70	53.76	28.36	1.03	0.73
Allographs selection$_1$	59.79	26.01	0.54	0.01	38.79	20.26	1.07	0.99	34.88	21.67	1.78	3.86
Alphabet writing$_2$	34.44	20.16	2.65	11.94	33.28	15.48	1.37	2.14	31.76	25.64	4.65	30.23
Alphabet cursive copy$_2$	63.64	34.03	1.56	3.10	64.69	32.11	1.46	3.63	66.33	41.35	2.64	10.92
Allographs selection$_2$	40.33	18.63	1.00	1.39	40.33	22.45	3.02	14.10	41.77	28.69	2.85	11.39
Speed												
Alphabet writing$_1$	1.34	0.53	0.83	-0.02	1.75	0.67	0.32	-0.83	2.08	0.76	0.49	0.74
Alphabet cursive copy$_1$	1.17	0.60	1.82	5.59	1.21	0.49	0.88	1.09	1.21	0.55	0.76	1.18
Allographs selection$_1$	1.19	0.42	1.16	0.47	1.61	0.61	0.45	-0.70	1.62	0.67	0.59	0.42
Alphabet writing$_2$	1.76	0.89	1.63	4.10	1.80	0.84	1.29	4.83	2.06	0.84	0.73	0.59
Alphabet cursive copy$_2$	1.13	0.46	0.47	1.07	1.23	1.30	7.59	65.08	1.12	0.41	0.91	1.95
Allographs selection$_2$	1.49	0.58	0.65	-0.61	1.59	0.67	0.90	0.46	1.54	0.63	0.50	-0.45
TI in Pauses												
Alphabet writing$_1$	4054.39	2345.25	2.08	6.24	2363.37	1294.82	1.91	4.46	1885.44	1148.03	2.82	10.50
Alphabet cursive copy$_1$	4123.56	1834.20	3.06	15.43	3490.12	1455.28	2.15	7.65	3281.50	1445.54	1.39	2.09
Allographs selection$_1$	3867.99	1469.83	0.95	2.68	2696.50	1008.17	0.77	0.75	2247.60	1227.37	2.50	8.84
Alphabet writing$_2$	2639.86	1700.09	2.44	9.24	1864.42	780.43	1.16	1.00	1626.40	947.81	2.74	10.56
Alphabet cursive copy$_2$	3904.98	2130.10	2.61	8.01	3226.84	1076.28	1.21	2.11	3238.70	1278.08	1.85	5.04
Allographs selection$_2$	2836.62	1292.46	1.46	2.96	2364.15	1166.21	2.36	8.65	2374.55	1407.33	3.00	12.17
Road Length												
Alphabet writing$_1$	8.96	2.73	0.10	-0.06	10.40	2.89	-0.06	1.03	10.70	2.49	0.60	0.56
Alphabet cursive copy$_1$	9.25	2.03	0.09	0.66	9.97	2.51	0.97	8.22	10.36	2.14	0.66	3.39
Alphabet manuscript copy$_1$	10.01	2.24	-0.15	-0.08	11.41	2.60	-0.57	2.29	11.62	2.52	0.46	8.95
Allographs selection$_1$	9.04	1.94	0.02	-0.10	9.92	1.97	-0.01	0.14	11.20	2.43	0.18	-0.41
Alphabet writing$_2$	10.56	3.57	0.46	-0.22	11.99	3.17	0.39	0.13	11.52	2.95	-0.23	1.10
Alphabet cursive copy$_2$	9.93	2.19	0.38	0.50	10.72	2.50	-0.49	1.67	10.45	1.94	-0.20	-0.40
Alphabet manuscript copy$_2$	11.30	2.47	1.22	4.49	11.68	3.32	-1.09	2.78	12.00	2.79	-0.24	2.56
Allographs selection$_2$	10.15	2.98	1.22	2.17	11.16	2.84	0.01	1.05	11.34	2.48	-0.27	0.47

Note*:* Pressure= Handwriting Pressure is expressed in Hz; Speed= Handwriting Speed is expressed in centimeters per second; TI Pauses = Time Invested in Pauses is expressed in milliseconds; Road Length = Handwriting automaticity in letter production is quantified by the quantity of letters written within a one-minute interval. $_{1,2}$ = first and second measurement time point

Table 2. Descriptive Statistics by Cohort for the Variables of Length, Fluency, Planning, Revision, and Organization in the Composition Letter

	Cohort 1 (1-2-4 grade)				**Cohort 2 (2-3-5 grade)**				**Cohort 3 (3-4-6 grade)**			
Writing Indicator	**M**	**DT**	**As**	**κ**	**M**	**DT**	**As**	**κ**	**M**	**DT**	**As**	**κ**
$Length_3$	62.05	20.95	0.38	0.42	72.90	22.28	0.36	-0.14	97.30	27.18	0.36	-0.05
$Fluency_3$	55.26	21.37	0.42	0.18	66.78	21.15	0.43	-0.13	91.44	26.93	0.35	0.16
$Planning_3$	2.98	1.07	0.14	-0.02	3.01	1.03	0.55	-0.29	3.21	0.97	0.33	-0.08
$Revision_3$	11.56	2.92	-0.84	10.42	11.63	2.71	-0.90	2.23	11.87	2.97	-0.72	1.18
$Organization_3$	2.16	0.94	0.98	0.71	2.78	1.04	0.43	-0.69	2.92	1.03	0.33	-0.44

Note*:* Length = number of words produced in the composition letter task; Fluency = number of correct words produced; Planning and Organization = were measured using *the coding scheme of the cognitive processes of writing* (Whitaker et al., 1994). Revision = *the written composition review instrument* (IRCE) (Arias-Gundín & García-Sánchez, 2006) was used to assess students' knowledge of processes and aspects involved during the review phase, 3 = third moment of evaluation.

For all models, except Model 4, the descriptive statistics indicated that some indicators showed asymmetry and kurtosis values exceeding the recommended thresholds (3.0 and 10.0) (Kline, 2005). To account for the nonnormal distribution, the study used the maximum likelihood (ML) estimation model and the Satorra-Bentler chi-square (SBχ2) for maximum likelihood estimation (Satorra & Bentler, 2001).

Model 1

Baseline model. The model, which included a latent variable (exogenous) of handwriting pressure at the 1st measurement moment and handwriting pressure at the 2nd measurement moment as an endogenous variable, demonstrated a good fit to the data, $SB\chi2$ (34) = 64.49, p <.01, $\chi2$ (34, N= 278) = 69.72, p <.05, CFI =.975, NFI =.952, NNFI= .959, GFI =.956, AGFI =.9, RMSEA =.062, (90% CI.041 -.082), SRMR =.051. In this model, the exogenous variable (handwriting pressure at the 1st measurement moment) explained 4% of the total variance in the endogenous variables of writing length, fluency, and revision, while the exogenous variable (handwriting pressure at the 2nd measurement moment) explained 22% of the variance in the endogenous variable (handwriting pressure at the 2nd measurement moment).

Configural model. The multigroup model demonstrated a favorable fit with the data, with $\chi2$ (110, N = 278) = 178.59, p <.01, CFI =.953, RMSEA =.082, p (RMSEA ≤ 0.05) = 1.00.

Measurement model. The model with restricted load factors did not show a decrease in fit, with $\chi2$ (102, N = 278) = 171.20, p <.01, CFI =.952, RMSEA =.067, p (RMSEA ≤ 0.05) = 1.00. The tests for differences in $\chi2$ and CFI indicated invariance, suggesting that the measures had the same meaning for the three cohorts. Once measurement invariance was established, the structural differences were tested.

Structural model. When load factors and structural paths were equitably constrained across cohorts, there was no decrease in fit, with $\chi2$ (132, N = 278) = 196.85, p <.05, CFI =.955, RMSEA =.073, p (RMSEA ≤ 0.05) = 1.00. The tests for differences in $\chi2$ and CFI indicated invariance in the loading and regression parameters across the three cohorts (25.64, df = 30, p = 0.69). Table 3 shows the standardized and nonstandardized coefficients for the three cohorts.

Table 3. Non-Standardized and Standardized Path Coefficients by Cohort and Course for the 1st Model.

Path/Route	Cohort 1 (1-2-4 grade)		Cohort 2 (2-3-5 grade)		Cohort 3 (3-4-6 grade)	
	Non-standardized	Standardized	Non-standardized	Standardized	Non-standardized	Standardized
$Pressure_1$						
Alphabet $writing_1$	1.00	0.82^{***}	1.00	0.69^{***}	1.00	0.81^{***}
Alphabet cursive $copy_2$	0.87^{***}	0.69^{***}	0.87^{***}	0.60^{***}	0.87^{***}	0.63^{***}
Allographs $selection_1$	1.00^{***}	0.83^{***}	1.00^{***}	0.82^{***}	1.00^{***}	0.74^{***}
$Pressure_1$ ➜ $Length^a$	$-.22^{*}$	$-.18^{*}$	$-.22^{*}$	$-.16^{*}$	$-.22^{*}$	$-.14^{*}$
$Pressure_1$ ➜ $Fluency^a$	$-.25^{*}$	$-.21^{*}$	$-.25^{*}$	$-.19^{*}$	$-.25^{*}$	$-.17^{*}$
$Pressure_1$ ➜ $Planning^a$	-.13	-.11	-.13	-.09	-.13	-.08
$Pressure_1$ ➜ $Revision^a$	$-.29^{**}$	$-.24^{**}$	$-.29^{**}$	$-.20^{**}$	$-.29^{**}$	$-.20^{**}$
$Pressure_1$ ➜ $Organization^a$	-.17	-.15	-.17	-.12	-.17	-.12
$Pressure_2$						
Alphabet $writing_2$	1.00	0.63^{***}	1.00	0.61^{***}	1.00	0.55^{***}
Alphabet cursive $copy_2$	0.95^{***}	0.59^{***}	0.95^{***}	0.56^{***}	0.95^{***}	0.67^{***}
Allographs $selection_2$	1.24^{***}	0.78^{***}	1.24^{***}	0.76^{***}	1.24^{***}	0.77^{***}
$Pressure_2$ ➜ $Length^a$	-.10	-.07	-.10	-.06	-.10	-.06
$Pressure_2$ ➜ $Fluency^a$	-.06	-.04	-.06	-.04	-.06	-.03
$Pressure_2$ ➜ $Planning^a$	0.15	0.10	0.15	0.09	0.15	0.09
$Pressure_2$ ➜ $Revision^a$	0.23	0.15	0.23	0.13	0.23	0.13
$Pressure_2$ ➜ $Organization^a$	-.05	-.03	-.05	0.03	-.05	-.03
$Pressure_1$ ➜ $Pressure_2$	0.40^{***}	0.52^{***}	0.40^{***}	0.47^{***}	0.40^{***}	0.48^{***}

Note*:* Pressure= Handwriting Pressure. For the comparisons between samples, see non-standardized measures, for the comparisons inside the sample, see standardized measures. [a] Unique factor indicator. (n = 278). * p < .05. ** p < .01. *** p < .001.

The standardized load factors obtained ranged from moderate to high values (*cohort 1* =.59-.83, *cohort 2* =.56-.82, *cohort 3* =.55-.81), indicating that the observed variables served as good indicators of the latent constructs. The direct effects showed a moderate relationship (r =.48) between the exogenous variable of handwriting pressure at the 1st measurement moment and handwriting pressure at the 2nd measurement moment. Handwriting pressure at the 1st measurement moment significantly influenced the endogenous variables writing length (β = -.14), fluency (β = -.17), and revision (β = -.20). However, handwriting pressure at the 2nd measurement moment stopped influencing all the evaluated endogenous variables at the 3rd measurement moment (see Figure 1).

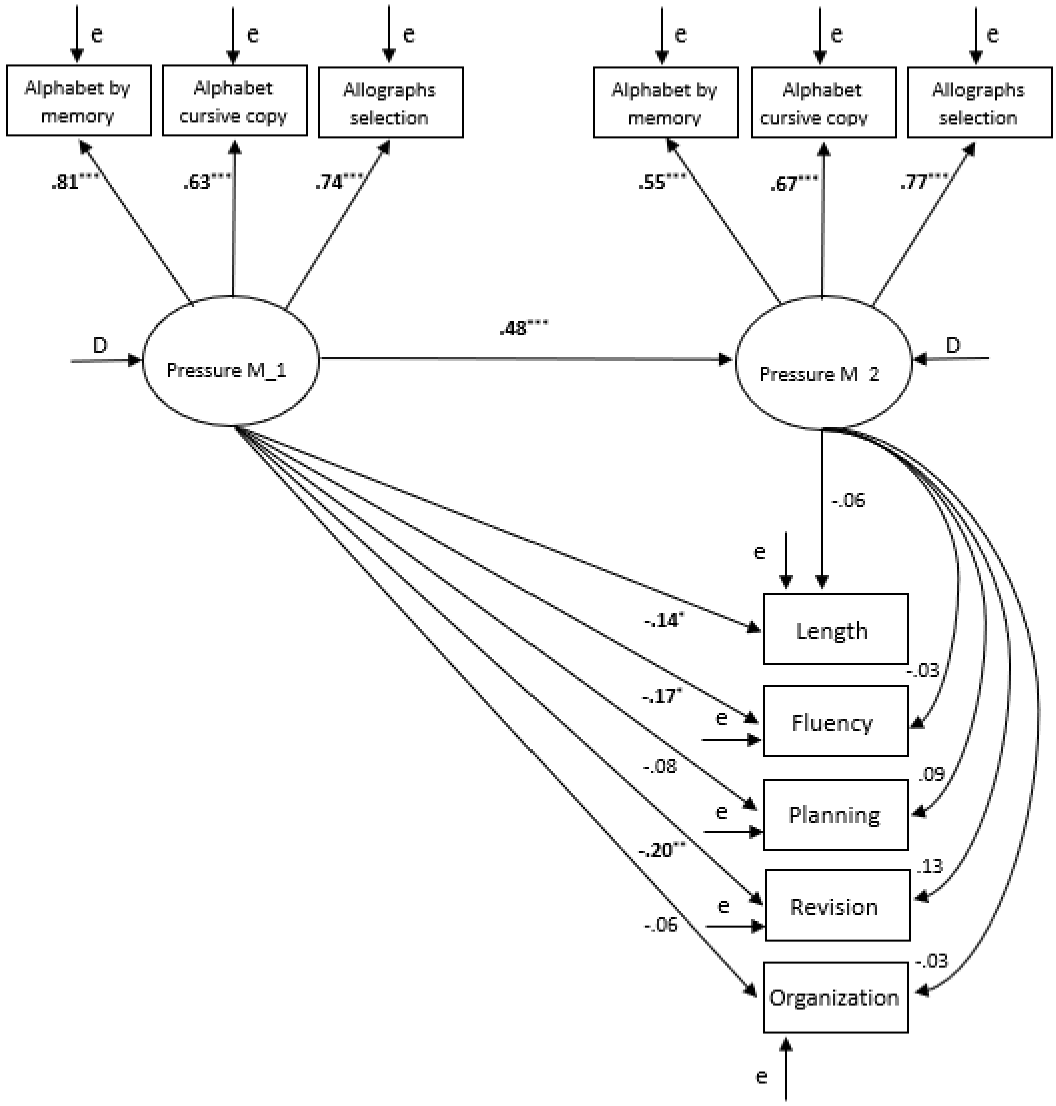

Figure 1. SEM for the Relation Between Handwriting Pressure, Writing Length, Fluency, Planning, Organization and Revision Processes. The Circles Represent Latent Variables, the Rectangles Denote Observable Variables, and the Arrows Depict Direct Pathways. e = error in measure; D = structural error.

Model 2

Baseline model. The evaluation of the model, which included the latent variable (exogenous) of handwriting speed at the 1st measurement moment and handwriting speed at the 2nd measurement moment as an endogenous variable, demonstrated a good fit to the data for the three cohorts. The SBχ2 test resulted in $SB\chi^2$ (32) = 35.56, p =.30, χ^2 (32, N = 278) = 45.49, p =.058, CFI =.99, NFI =.967, NNFI =.983, GFI =.97, AGFI =.929, RMSEA =.039, (90% CI.00 -.063), SRMR =.039. In this model, the exogenous variable (handwriting speed at the 1st measurement moment) explained 6% of the total variance in writing length, 7% in fluency, and 2% in revision, while the exogenous variable (handwriting speed at the 2nd measurement moment) explained 32% of the variance in handwriting speed at the 2nd measurement moment.

Configural model. The multigroup model demonstrated a good fit to the data, with χ^2 (104, N = 278) = 140.53, p <.05, CFI =.973, RMSEA =.062, p (RMSEA ≤ 0.05) = 1.00.

Measurement model. The model with restricted load factors did not show a decrease in fit, with χ^2 (96, N = 278) = 125.93, p <.05, CFI =.978, RMSEA =.058, p (RMSEA ≤ 0.05) = 1.00. The tests for differences in χ2 and CFI indicated invariance, suggesting that the measures had the same meaning across the three cohorts. Once measurement invariance was established, the structural differences were tested.

Structural model. When load factors and structural paths were equitably constrained across cohorts, there was no decrease in fit, with χ^2 (126, N = 278) = 158.95, p <.05, CFI =.976, RMSEA =.053, p (RMSEA ≤ 0.05) = 1.00. The tests for differences in χ2 and CFI indicated invariance in the loading and regression parameters across the three cohorts (33.02, *df* = 30, *p* = 0.32). Table 4 shows the standardized and nonstandardized coefficients for the three cohorts.

Table 4. Non-Standardized and Standardized Path Coefficients by Cohort and Course for the 2nd Model.

Path/Route	Cohort 1 (1-2-4 grade)		Cohort 2 (2-3-5 grade)		Cohort 3 (3-4-6 grade)	
	Non-standardized	Standardized	Non-standardized	Standardized	Non-standardized	Standardized
$Speed_1$						
Alphabet $writing_1$	1.00	0.78***	1.00	0.64***	1.00	0.74***
Alphabet cursive $copy_1$	0.84***	0.65***	0.84***	0.55***	0.84***	0.58***
Allographs $selection_1$	0.94***	0.70***	0.94***	0.66***	0.94***	0.70***
$Speed_1$ → Length[a]	0.31**	0.25**	0.31**	0.22**	0.31**	0.22**
$Speed_1$ → Fluency[a]	0.32**	0.25**	0.32**	0.22**	0.32**	0.22**
$Speed_1$ → Planning[a]	-.01	-.01	-.01	-.008	-.01	-.009
$Speed_1$ → Revision[a]	.25*	0.20*	0.25*	.17*	.25*	0.18*
$Speed_1$ → Organization[a]	-.005	-.004	-.005	-.003	-.005	-.004
$Speed_2$						
Alphabet $writing_2$	1.00	0.79***	1.00	0.74***	1.00	0.77***
Alphabet cursive $copy_2$	0.55***	0.43***	0.55***	0.38***	.55***	0.45***
Allographs $selection_2$	0.99***	0.73***	0.99***	0.75***	.99***	0.77***
$Speed_2$ → Length[a]	0.06	0.04	0.06	0.05	.06	0.04
$Speed_2$ → Fluency[a]	0.07	0.05	0.07	0.05	.07	0.05
$Speed_2$ → Planning[a]	-.01	-.01	-.01	-.01	-.01	-.01
$Speed_2$ → Revision[a]	-.10	-.07	-.10	-.08	-.10	-.08
$Speed_2$ → Organization[a]	0.12	0.10	0.12	-.10	.12	0.10
$Speed_1$ → $Speed_2$	0.62***	0.66***	0.62***	0.53***	.62***	0.56***

Note: Speed= Handwriting Speed. For the comparisons between samples, see non-standardized measures, for the comparisons inside the sample, see standardized measures. a Unique factor indicator. (n = 278). * p < .05. ** p < .01. *** p < .001

All the standardized load factors obtained exhibited moderate to high ranges across the three cohorts: *cohort 1* (range:.43 -.79), *cohort 2* (range:.38 -.75), and *cohort 3* (range:.45 -.77). These findings suggest that the observed variables served as robust indicators of the latent constructs. The direct effects revealed a moderate relationship (r =.56) between the exogenous factor of handwriting speed at the 1st measurement moment and the endogenous variable of handwriting speed at the 2nd measurement moment. Specifically, the handwriting speed at the 1st measurement moment significantly influenced the endogenous variables of writing length (β =.22), fluency (β =.22), and revision (β =.18). However, at the 3rd measurement moment, the influence of handwriting speed at the 2nd measurement moment on any of the evaluated endogenous variables was no longer significant (see Figure 2).

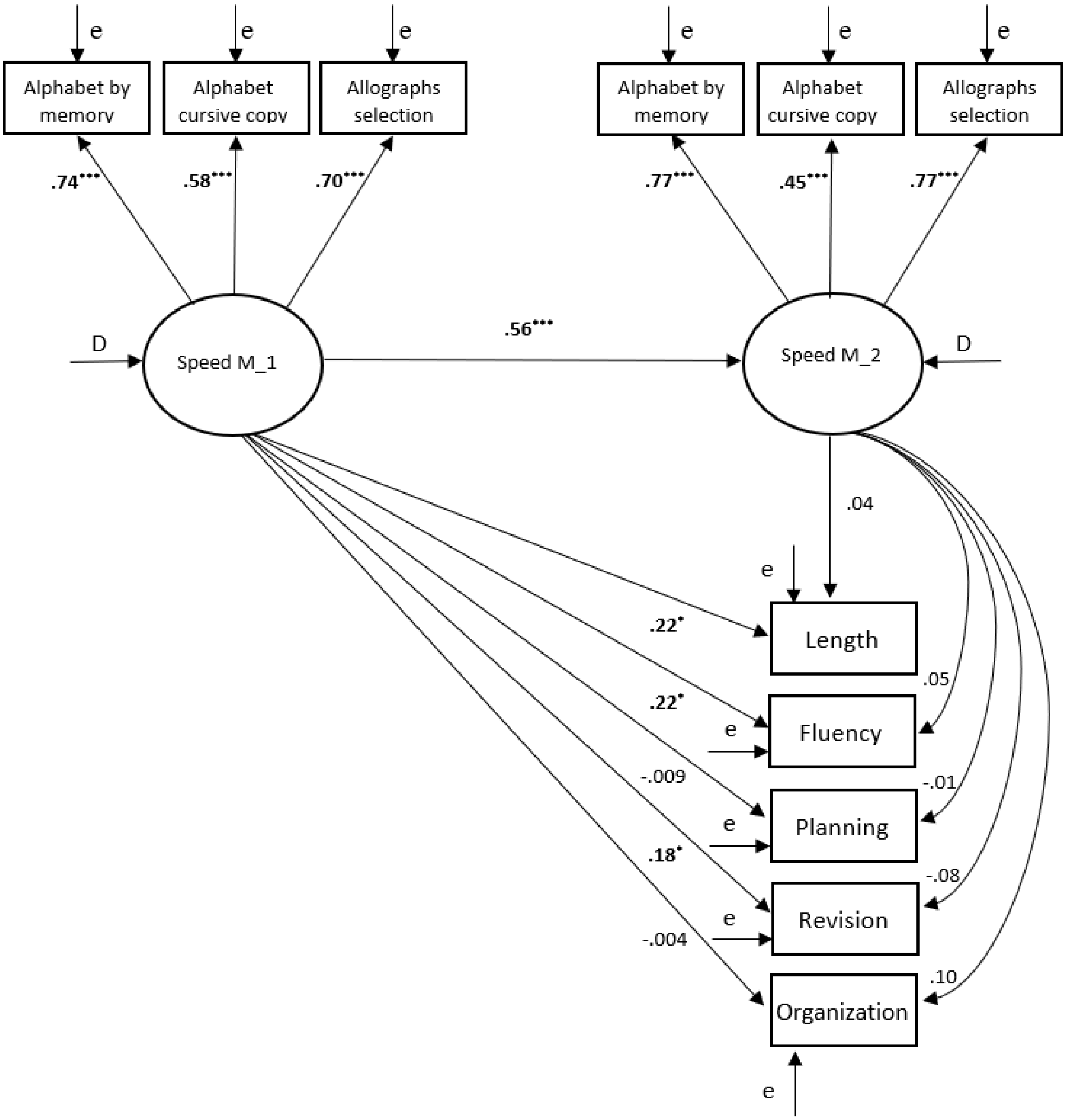

Figure 2. SEM for the Relation Between Handwriting Speed, Writing Length, Fluency, Planning, Organization and Revision Processes. The Circles Represent Latent Variables, the Rectangles Denote Observable Variables, and the Arrows Depict Direct Pathways. e = error in measure; D = structural error.

Model 3

The baseline model, which evaluated the relationship between the exogenous latent variable of time invested in pauses at the 1st measurement moment and the endogenous variable of time invested in pauses at the 2nd measurement moment, indicated a good fit for the data in the three cohorts. The fit indices were as follows: $SB\chi^2$ (34) = 57.53, p <.01, χ^2 (34, N = 277) = 68.37, p <.001, CFI =.974, NFI =.95, NNFI =.957, GFI =.956, AGFI =.899, RMSEA =.06, (90% CI.039 -.081), SRMR =.044. In this model, the endogenous variables of fluency and revision were explained by the exogenous variable in 29% and 10% of the total variance, respectively, while the endogenous variable of time invested in pauses at the 2nd measure moment was explained by the exogenous variable by 60%.

Configural model. The multigroup model demonstrated a good fit to the data, with χ^2 (110, N = 277) = 160.25, p <.01, CFI =.962, RMSEA =.070, P (rmsea ≤ 0.05) = 1.00.

Measurement model. The inclusion of restricted load factors did not result in a decrease in fit, as indicated by the following fit indices: χ^2 (102, N = 277) = 156.19, p <.01, CFI =.959, RMSEA =.076, p (RMSEA ≤ 0.05) = 1.00. The differences in $\chi2$ and CFI tests confirmed invariance. The chi-square difference in the multigroup model was 4.06 (df = 8; p = 0.85). These results indicate that there were no significant differences in the load factors among the three cohorts, suggesting that the measures had the same meaning across all cohorts.

Structural model. When load factors and structural paths were equitably constrained across cohorts, there was no decrease in fit, as indicated by the following fit indices: χ^2 (132, N = 277) = 182.43, p <.01, CFI =.962, RMSEA =.064, p (RMSEA ≤ 0.05) =1.00. The difference tests in $\chi 2$ and CFI supported the invariance of the model. Similar invariance was also observed for the loading and regression parameters across the three cohorts, with a chi-square difference of 26.24 (df = 30; p = 0.66). Table 5 shows the standardized and nonstandardized coefficients for the three cohorts.

Table 5. Non-Standardized and Standardized Path Coefficients by Cohort and Course for the 3rd Model.

Path/Route	Cohort 1 (1-2-4 grade)		Cohort 2 (2-3-5 grade)		Cohort 3 (3-4-6 grade)	
	Non-standardized	Standardized	Non-standardized	Standardized	Non-standardized	Standardized
TI Pauses$_1$						
Alphabet writing$_1$	1.00	0.75***	1.00	0.61***	1.00	0.72***
Alphabet cursive copy$_1$	0.62***	0.43***	0.62***	0.34***	0.62***	0.46***
Allographs selection$_1$	0.82***	0.62***	0.82***	0.50***	0.82***	0.61***
TI Pauses$_1$ → Length[a]	-.37*	-.26	-.37*	-.23	-.37*	-.27
TI Pauses$_1$ → Fluency[a]	-.48*	-.34*	-.48*	-.30*	-.48*	-.36*
TI Pauses$_1$ → Planning[a]	-.18	-.14	-.18	-.10	-.18	-.14
TI Pauses$_1$ → Revision[a]	-.74**	-.54**	-.74**	-.41**	-.74**	-.53**
TI Pauses$_1$ → Organization[a]	-.16	-.13	-.16	-.09	-.16	-.12
TI Pauses$_2$						
Alphabet writing$_2$	1.00	0.68***	1.00	0.66***	1.00	0.78***
Alphabet cursive copy$_2$	0.51***	0.38***	0.51***	0.34***	0.51***	0.39***
Allographs selection$_2$	0.86***	0.67***	0.86***	0.57***	0.86***	0.64***
TI Pauses$_2$ → Length[a]	-.34*	-.25	-.34*	-.25	-.34*	-.25
TI Pauses$_2$ → Fluency[a]	-.30	-.22	-.30	-.22	-.30	-.22
TI Pauses$_2$ → Planning[a]	-.09	-.07	-.09	-.06	-.09	-.06
TI Pauses$_2$ → Revision[a]	0.50	0.38	0.50	0.34	0.50	0.36
TI Pauses$_2$ → Organization[a]	-.25	-.20	-.25	-.17	-.25	-.18
TI Pauses$_1$ → TI Pauses$_2$	0.83***	0.80***	0.83***	0.69***	0.83***	0.84***

Note*:* TI Pauses = Time Invested in Pauses. For the comparisons between samples, see non-standardized measures, for the comparisons inside the sample, see standardized measures. [a] Unique factor indicator. (n = 278). * p < .05. ** p < .01. *** p < .001.

All the standardized load factors obtained exhibited moderate and high ranges across the cohorts (*cohort 1* =.38 -.75; *cohort 2* =.34 -.66; and *cohort 3* =.39 -.78). These findings indicate that the observed variables served as good indicators of the latent constructs. The direct effects revealed a strong relationship (r =.84) between the exogenous factor, time invested in pauses at the 1st measurement moment, and the endogenous variable, time invested in pauses at the 2nd measurement moment. Specifically, time invested in pauses at the 1st measure moment had a significant negative influence on the endogenous variable of revision (β = -.53), as well as a negative influence on fluency (β = -.36). However, at the 3rd measurement moment, time invested in pauses at the 2nd measurement moment no longer significantly influenced any of the evaluated endogenous variables (see Figure 3).

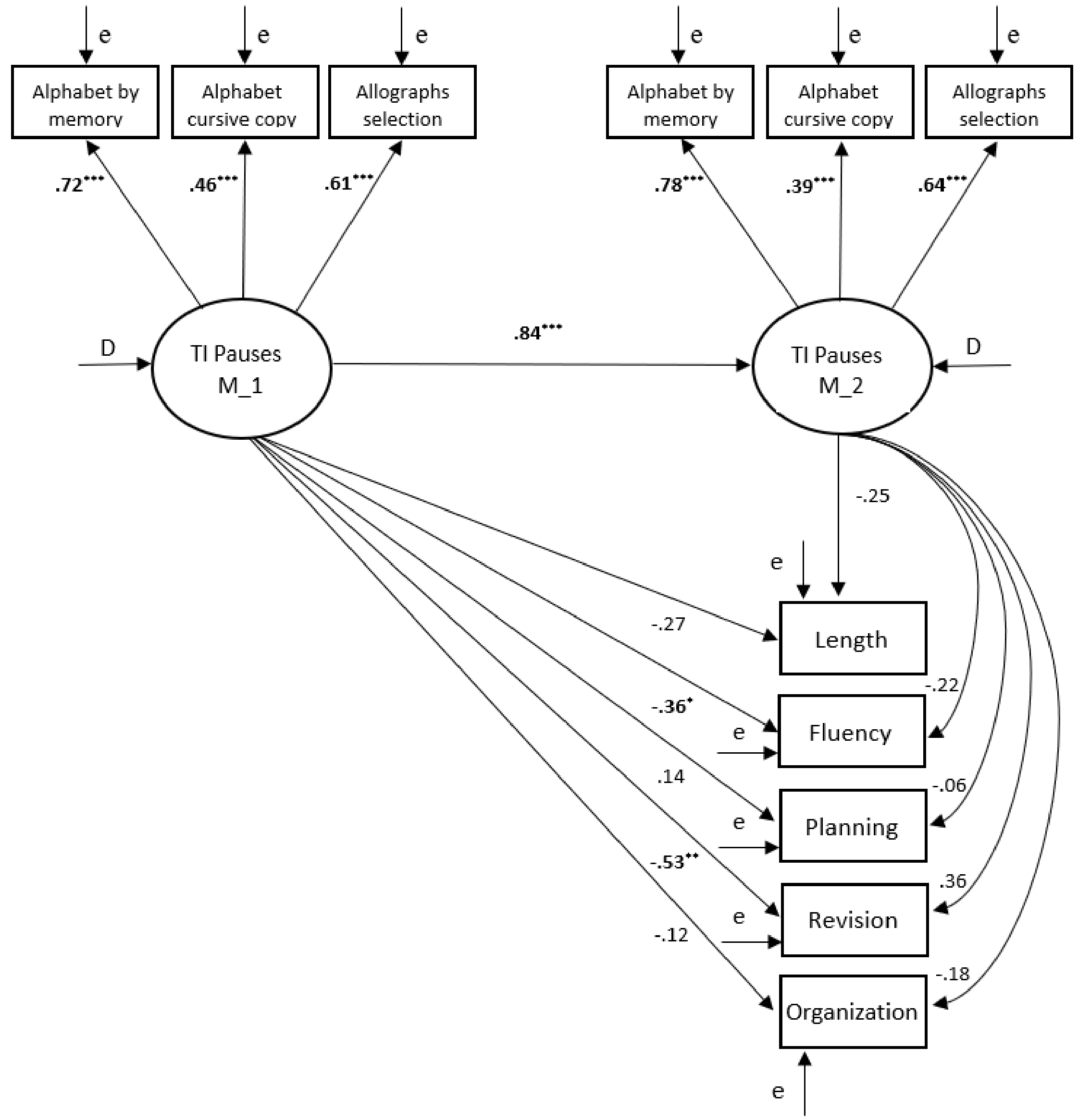

Figure 3. SEM for the Relation Between Time Invested in Pauses, Writing Length, Fluency, Planning, Organization and Revision Processes. The Circles Represent Latent Variables, the Rectangles Denote Observable Variables, and the Arrows Depict Direct Pathways. e = error in measure; D = structural error.

Model 4

Baseline model**.** The evaluation of the model, utilizing road length as the latent variable (exogenous) at the 1st measurement moment and handwriting automaticity at the 2nd measurement moment as the endogenous variable, demonstrated a good fit for the data across the three cohorts: χ^2 (55, N = 278) = 94.50, p <.01, CFI =.971, NFI =.935, NNFI =.959, GFI =.95, AGFI =.957, RMSEA =.051, (90% CI.033 -.068), SRMR =.048. In this model, the endogenous variables—writing length, fluency, planning, and organizing—are minimally explained by the exogenous variable (automaticity at the 1st measure moment), accounting for 5%, 6%, 5%, and 5% of the total variance, respectively. However, the endogenous variable of handwriting automaticity at the 2nd measurement moment is explained by the exogenous variable to a larger extent, with an explanatory power of 37%.

Configural model. The multigroup model demonstrated a good fit to the data, with χ^2 (177, N = 278) = 266.42, p <.001, CFI =.937, RMSEA =.074, p (RMSEA ≤ 0.05) = 1.00.

Measurement model. The model with restricted load factors demonstrated a good fit, indicating no decrease in fit: χ^2 (96, N = 278) = 243.85, p <.001, CFI =.945, RMSEA =.072, p (RMSEA ≤ 0.05) = 1.00. The differences in χ2 and CFI tests indicate measurement invariance. The chi-square difference in the multigroup model was 22.57 (df = 12; p = 0.03). There were no significant differences in the load factors among the three cohorts, indicating that the measures held consistent significance across all cohorts.

Structural model. Restricting the load factors and structural paths to be equal among the different groups did not result in a decrease in fit: χ^2 (199, N = 277) = 286.27, p <.001, CFI =.939, RMSEA =.069, p (RMSEA ≤ 0.05) = 1.00. The differences in $\chi 2$ and CFI tests reflect invariance. Similar invariance was found for the loading and regression parameters across the three cohorts, with a chi-square difference of 42.42 (df = 34; p =.15). Table 6 shows the standardized and nonstandardized coefficients pertaining to the three cohorts.

Table 6. Non-Standardized and Standardized Path Coefficients by Cohort and Course for the 4th Model.

Path/Route	Cohort 1 (1-2-4 grade)		Cohort 2 (2-3-5 grade)		Cohort 3 (3-4-6 grade)	
	Non-standardized	Standardized	Non-standardized	Standardized	Non-standardized	Standardized
Road length₁						
Alphabet writing₁	1.00	0.57***	1.00	0.46***	1.00	0.52***
Alphabet cursive copy₁	1.13***	0.59***	1.13***	0.53***	1.13***	0.60***
Alphabet manuscript copy₁	1.09***	0.59***	1.09***	0.52***	1.09***	0.55***
Allographs selection₁	1.20***	0.66***	1.20***	0.55***	1.20***	0.67***
RL₁ → Length[a]	0.44*	0.24*	0.44*	0.21*	0.44*	0.23*
RL₁ → Fluency[a]	0.51*	0.28*	0.51*	0.24*	0.51*	0.27*
RL₁ → Planning[a]	0.50*	0.28*	0.50*	0.22*	0.50*	0.27*
RL₁ → Revision[a]	0.28	0.15	0.28	0.12	0.28	0.14
RL₁ → Organization[a]	0.57**	0.33**	0.57**	0.26**	0.57**	0.30**
Road lenght₂						
Alphabet writing₁	1.00	0.58***	1.00	0.56***	1.00	0.51***
Alphabet cursive copy₂	1.04***	0.56***	1.04***	0.61***	1.04***	0.54***
Alphabet manuscript copy₂	1.12***	0.63***	1.12***	0.63***	1.12***	0.59***
Allographs selection₂	1.19***	0.65***	1.19***	0.71***	1.19***	0.64***
RL₂ → Length[a]	-.02	-.01	-.02	-.01	-.02	-.01
RL₂ → Fluency[a]	-.06	-.03	-.06	-.03	-.06	-.03
RL₂ → Planning[a]	-.09	-.04	-.09	-.05	-.09	-.04
RL₂ → Revision[a]	-.12	-.06	-.12	-.07	-.12	-.06
RL₂ → Organization[a]	-.13	-.07	-.13	-.08	-.13	-.07
RL₁ → Automat₂	0.65***	0.67***	0.65***	0.51***	0.65***	0.66***

Note*:* RL= Road Length; for the comparisons between samples, see non-standardized measures, for the comparisons inside the sample, see standardized measured. [a] Unique factor indicator. (n = 278). * p < .05. ** p < .01. *** p < .001.

All the standardized load factors obtained demonstrated moderate ranges (*cohort 1*=.56 -.66; *cohort 2* =.46 -.71; and *cohort 3* =.51 -.67), indicating that the observed variables were reliable indicators of the underlying constructs. The direct effects revealed a moderate relationship (r =.66) between the exogenous factor, handwriting automaticity at the 1st measurement moment, and the endogenous variable, handwriting automaticity at the 2nd measurement moment. Handwriting automaticity at the 1st measurement moment significantly influenced the endogenous variables: writing length (β =.23), fluency (β =.27), planning (β =.27), and organizing (β =.30). However, the influence of handwriting automaticity on the endogenous variables diminished at the 2nd measurement moment (see Figure 4).

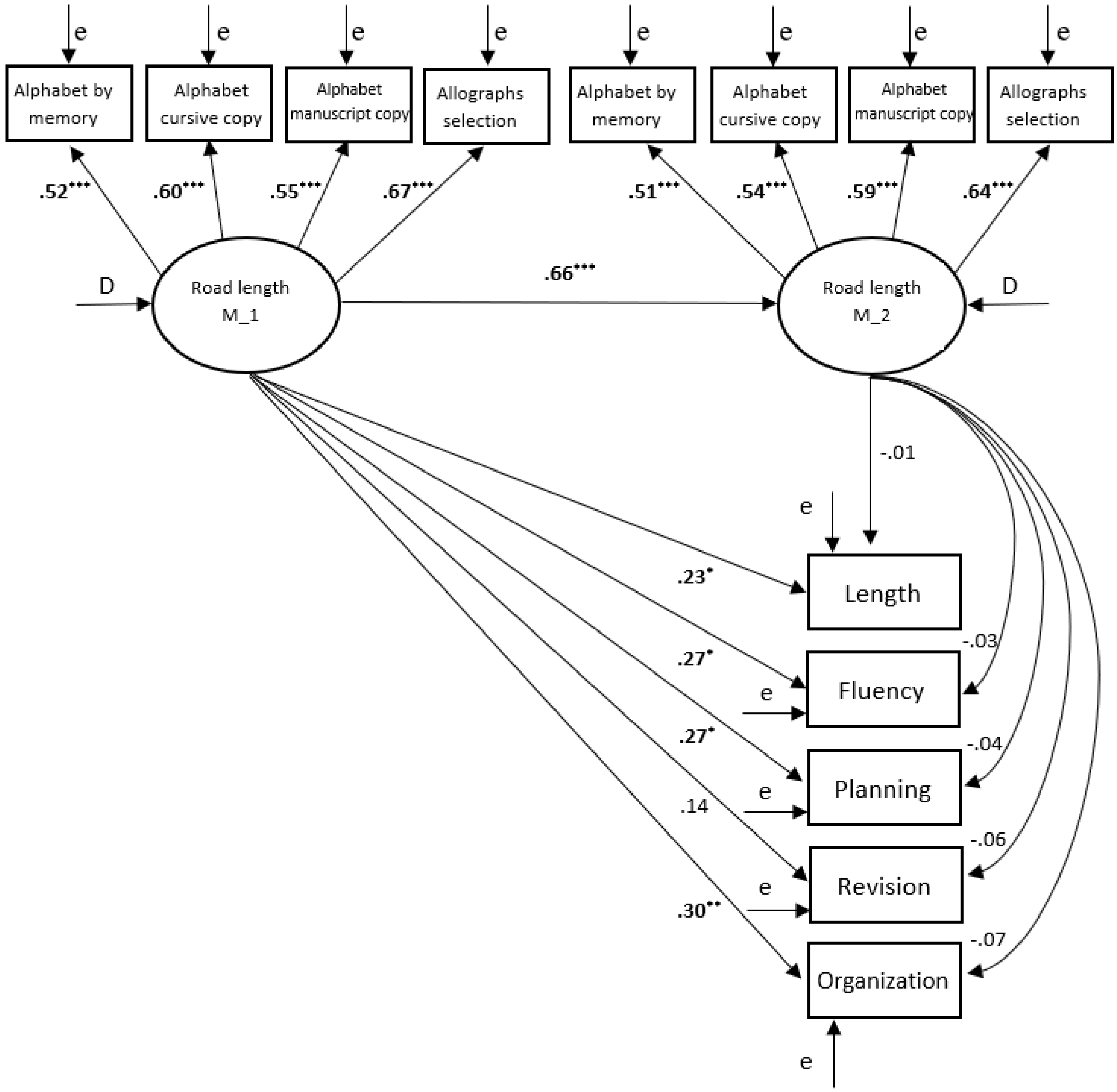

Figure 4. SEM for the Relation Between Handwriting Automaticity, Writing Length, Fluency, Planning, Organization and Revision Processes. The circles Represent Latent Variables, the Rectangles Denote Observable Variables, and the Arrows Depict Direct Pathways. e = error in measure; D = structural error.

Discussion

This study aims to investigate the proficiency of early-stage Spanish writers in terms of transcription skills, particularly handwriting fluency, as well as their ability for text generation while employing writing by pen. Within this context, the present research also investigated the developmental progression of transcription skills (specifically, handwriting) by recording and analyzing graphonomic measures. The observed regression effect for all graphonomic measures was found to be statistically significant (i.e., .48 for pressure, .56 for speed, .84 for pauses, and .66 for road length), suggesting a strong and positive relationship between the latent factors across the two temporal assessments. Research on typically developing children in the early stages of primary education consistently reveals age-related trends. As children progress, aspects of their handwriting, such as stroke duration, number of strokes, pause duration, and vertical/horizontal dimensions, generally decrease, while pen velocity tends to increase. (see for a review, Coradinho et al., 2023).

Pressure (Model 1)

Our initial hypothesis suggested that students in the early stages of primary education would likely demonstrate elevated levels of handwriting pressure while producing graphemes, potentially impacting the production and quality of their written compositions. Contrary evidence from studies conducted in the Italian language, particularly in the second year of literacy, reveals a reduction in pressure during writing, indicating a higher average. This pattern aligns with the characteristics of a transparent language, as demonstrated in the research conducted by Capellini et al. (2020). Nevertheless, in the present study, the regression coefficients observed during the first measurement moment indicate negative associations between handwriting pressure and writing length ($\beta = -.14$), fluency ($\beta = -.17$), and revision ($\beta = -.20$). Alamargot and Morin (2015) conducted a study comparing graphonomic measures in French students' writing performances in 2nd and 9th grades. They found that the acquisition of motor programs for letter formation is slow and demanding before the ages of 9 and 10. Results showed that 2nd-grade students exerted greater handwriting pressure than 9th-grade students. The negative impact of handwriting pressure on writing length, fluency, and revision suggests that it reflects the effort invested in executing the motor pattern. If this regulation is not fully achieved in the 1st measurement moment, it adversely affects writing production and quality in the 3rd measurement moment. However, the influence of handwriting pressure weakens when examining its association with writing during the 3rd measurement moment.

Speed (Model 2)

In a recent study involving Spanish students, the findings indicated a substantial increase in handwriting speed from the age of 8 to 10, which then stabilized through the age of 12 (Afonso et al., 2020). Handwriting speed involves the rapid execution of involuntary movements during handwriting and indicates whether the motor pattern has been unconsciously automatized. In our hypothesis, we proposed that with practice in motor program execution and neurocognitive maturation, this graphonomic variable imposes less cognitive overload and allows the writer to allocate more attention to central cognitive processes. This is supported by the regression coefficients observed between handwriting speed at the 1st measurement moment and writing length (β =.22), fluency (β =.22), and revision (β =.18) at the 3rd measurement moment. The structural relationships between handwriting speed at the 1st measurement moment and writing length, fluency, and revision align with findings reported in a Norwegian study (Karlsdottir & Stefansson, 2002). In a longitudinal study involving students from 1st to 5th grade in primary education, the authors found that handwriting speed moderately affects the quality of writing and reported an increase in handwriting speed between 3rd and 5th grade. We suggest that handwriting speed during the execution of graphemes serves as an indicator of appropriate visuomotor integration, which is crucial for visual feedback during the early years of primary school writing.

Pauses (Model 3)

Improving transcription skills over time correlates with a reduction in pauses during handwriting execution in the writing process (Pascual et al., 2023). These authors found that 3rd graders made more and longer pauses than 5th graders, though the study was made in a language with a semi-consistent orthography (Catalan). In our hypothesis, we suggested that as neurocognitive maturity and handwriting practice develop, the graphonomic variable, represented by pause time, reflects the time spent searching for the correct grapheme and its motor pattern. A decrease in pause time indicates faster retrieval of information from long-term memory, supported by the negative regression coefficients observed between pause time at the 1st measurement moment and revision (β = -.36) in this study. However, pause time at the 2nd measurement moment loses significance in relation to endogenous variables. This model suggests that excessive pause time during early primary grades can impede the development of high-level writing abilities. In the present research, fluency (β = -.36) and revision (β = -.53) were negatively influenced by the exogenous variable (pause time at the 1st measurement moment). These structural relationships reflect that, during the 1st measurement moment, the subject has not yet acquired immediate access to the graphemic storing buffer, hindering motor patterns. As pause time decreases at the 2nd measurement moment, the weakened relationship with writing fluency and revision at the 3rd measurement moment can be attributed to the statistical influence of the first-order endogenous variable on the subsequent endogenous variables. These findings align with Alamargot and Fayol's (2009) and Van Galen's (1991) model, providing empirical evidence that pause time during writing reflects a conflict in searching for a specific motor pattern in long-term memory, indicating intricate cognitive processing and cognitive load. Kandel and Perret (2015) suggest that delays in planning semantic representation or translating linguistic forms lead to pauses in graphomotor execution, supporting our model's assertion that pause duration and frequency signify discernible markers of cognitive processing and cognitive load.

Road Length (Model 4)

In the scientific literature, there is no consensus regarding handwritten road length, as some studies suggest a decrease in road length with advancing age, while others report the absence of any significant relationship between handwritten road length and age (for a comprehensive review, see Coradinho et al., 2023). In the present study, as children achieve greater proficiency in writing speed, they can execute motor programs more efficiently, thereby releasing cognitive resources for engagement in higher-order cognitive processes and the development of more extensive and sophisticated textual compositions. This is supported by the regression coefficients observed between road length at the 1st measurement moment and writing length (β =.23), fluency (β =.27), planning (β =.27), and organization (β =.30) at the 3rd measurement moment. Teulings and Schomaker (1993) suggested that during handwriting instruction, children acquire the ability to generate distinct movement patterns for each grapheme, and these patterns are combined to form more complex spelling units. The consistency of letter shapes through repetition indicates the presence of motor patterns for each letter. Coradinho et al. (2023) observed that decreased handwriting quality was correlated with an increased road length. On the contrary, improved handwriting quality was linked to a reduced relative pen-down duration. The results obtained in the analysis of road length illustrate how handwriting automaticity relates to a central process involving immediate access to the graphemic storing buffer and graphomotor memory. As automaticity increases at the 2nd measurement moment, influenced by the exogenous variable, the structural relationship between the endogenous variable at the 2nd measurement moment and the endogenous variables (writing length, fluency, planning, and revision processes) weakens and becomes insignificant at the 3rd measurement moment.

In sum, in transparent orthographies like Turkish and Finnish, prior studies using product-based measures revealed a diminishing impact of transcription skills, particularly handwriting, on writing production beyond 1st grade (Babayigit & Stainthorp, 2011; Lerkkanen et al., 2004). Conversely, in opaque orthographies, this effect persists into intermediate grades, linked to the language's orthographic depth (Berninger & Swanson, 1994; Graham et al., 1997). However, employing graphonomic measures for real-time handwriting suggests that the sustained impact of transcription skills extends beyond 1st grade, predominantly observed in Cohort 1 (early grades, around 3rd grade). This implies that achieving greater speed, reduced pressure, and distance, along with fewer pauses in handwriting, may occur earlier in transparent orthographies, associated with cognitive resource conservation. Nevertheless, replication in a language with opaque orthography is needed, with the assumption that handwriting automation's impact on text generation would be more pronounced, given the additional cognitive resources required. The influence of spelling ability on handwriting production rates, especially in opaque orthographies, is conceivable, as supported by prior research (Kandel & Perret, 2015; Kandel & Valdois, 2005; Mangen & Balsvik, 2016).

The study's implications for early-grade writing instruction and assessment are significant. The prolonged influence of transcription skills, especially handwriting, in transparent orthographies beyond the 1st grade emphasizes the need for targeted early interventions. The integration of graphonomic measures for real-time handwriting evaluation offers a nuanced understanding of cognitive and motor processes in writing, suggesting their incorporation into assessment strategies. Prioritizing aspects like increased speed, reduced pressure, and fewer pauses in handwriting may enhance cognitive resource conservation and writing fluency. These insights offer valuable guidance for educators striving to optimize writing outcomes in the early stages of education.

Conclusions

The main conclusion of this study is that the significant impact of handwriting on text production was primarily observed in Cohort 1 (early grades), while no significant effects were found in Cohort 2 (intermediate grades). This suggests that the importance of handwriting in text production may be more pronounced during the initial stages of writing development when students are acquiring foundational writing skills in a transparent orthography. That is, based on the findings obtained, the influence of handwriting on text production diminishes beyond the 2nd measurement moment (Cohort 2) and is no longer significant in relation to the endogenous variables measured at the 3rd measurement moment (Cohort 3). Therefore, it can be inferred that the influence of handwriting on text production starts to decrease by the time students reach the intermediate grades, which in this study corresponds to the 3rd-4th-6th grade cohort. As students progress to higher grades, other factors or writing-related skills may start to play a more prominent role in text production. However, further research is needed to fully understand the reasons behind these differences and how other factors may influence the outcomes.

The study's implications for early-grade writing instruction and assessment are significant. The prolonged influence of transcription skills, especially handwriting, in transparent orthographies beyond the 1st grade emphasizes the need for targeted early interventions. The integration of graphonomic measures for real-time handwriting evaluation offers a nuanced understanding of cognitive and motor processes in writing, suggesting their incorporation into assessment strategies. Prioritizing aspects like increased speed, reduced pressure, and fewer pauses in handwriting may enhance cognitive resource conservation and writing fluency. The study advocates for further research in languages with deep orthographies, anticipating a more pronounced impact of handwriting automation on text generation. Integrating spelling instruction, particularly addressing irregular words, and exploring technological tools like digitizing tablets for recording graphonomic measures present promising avenues to enhance early writing instruction. These insights offer valuable guidance for educators striving to optimize writing outcomes in the early stages of education.

Recommendations

Drawing from the findings of this study, it is evident that handwriting plays a pivotal role in the early writing development of students. Therefore, it is imperative that writing instruction, particularly in the initial grades, places substantial emphasis on fostering accurate and fluent letter formation skills in young learners. The study's recommendations underscore the importance of an early focus on handwriting skills, particularly in Cohort 1, where significant effects on text production were discerned. For intermediate grades (Cohort 2), adaptive teaching approaches that balance handwriting with other writing aspects are suggested. Key strategies include continuous monitoring of graphonomic measures, integrated curriculum development, and sustained professional development for educators. These insights aim to guide educators, researchers, and policymakers in optimizing writing instruction throughout primary school. Emphasizing foundational skills in the early years, coupled with adopting adaptive methods for later stages, is pivotal for cultivating comprehensive writing proficiency.

Limitations

The present study, however, is not exempt from certain limitations. It is imperative to acknowledge these limitations and elucidate potential avenues for future research to further advance our understanding of writing screening research. First, there could be other factors or variables that have a stronger influence on the outcome measures compared to the latent factor measured at Time 2. These unaccounted factors might have a more direct or significant impact on the outcomes, thereby overshadowing the predictive power of the Time 2 latent factor. In accordance with theoretical frameworks of writing, as exemplified by the "not-so-simple view of writing" (Berninger & Amtmann, 2003; Berninger & Winn, 2006), automaticity in handwriting may be one of the factors that influence the translation process, but it may not be the only factor that affects text production. Other factors, such as working memory, oral language skills, and attention, may also play a role in the relationship between automaticity in handwriting and text production. Second, the characteristics of the sample or participants may influence the relationship between the latent factor at Time 2 and the outcome measures. Individual differences, developmental changes, or specific contextual factors may interact with the latent factor at Time 2, leading to a nonsignificant relationship with the outcome measures. Third, the limitation in sample size could impact the generalizability of the findings to broader populations. Future research endeavors might benefit from incorporating more extensive samples to validate and extend the conclusions presented herein. And finally, the relatively limited quantity of classrooms precluded the utilization of more intricate statistical multilevel models (such as random slopes models) for assessing the predictive efficacy of classroom-related variables on students' writing performance.

Ethics Statements

This study was conducted according to the Research Ethics Committee guidelines from La Universidad de la Laguna (https://viinv.ull.es/ceiba/). Prior to the administration of the instrument, authorization was requested from the school and families for the study to be conducted.

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Conflicts of interest/Competing interests

We have no known conflict of interest to disclose.

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