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A Cross-Lagged Panel Analysis of Reading, Writing, and Math in First-Grade Elementary Students

Estudio longitudinal de panel sobre las relaciones entre lectura, escritura y matemáticas en estudiantes de primer grado de primaria

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Abstract

This longitudinal cross-lagged panel study, employing a data-driven approach, investigated the intricate relationships among reading, writing, and math during the learning process of first-grade elementary students. A sample of 392 first-grade students was selected, and assessments were conducted at three different time points: the beginning, middle, and end of the school year. The results revealed strong stability in the measures of reading, writing, and math across the three assessment points. Concurrent and temporal effects were analyzed, revealing bidirectional influences and underscoring the impactful role of reading. Model stability was assessed through resampling, which demonstrated consistency in a high percentage of configural vs. restricted comparisons, along with an RMSEA of less than 0.7. The educational implications of these findings are explored, emphasizing their relevance for enhancing learning processes in reading, writing, and math, particularly as concerns the interactions among these three domains.

Keywords: cross-lagged longitudinal panel, reading, writing, math

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Resumen

Este estudio longitudinal de panel con análisis cruzado, utilizando un enfoque basado en datos, investigó las relaciones entre la lectura, escritura y matemáticas durante el proceso de aprendizaje del alumnado de primer grado de primaria. Para ello se seleccionó una muestra de 392 estudiantes de primer grado y se llevó a cabo una evaluación en tres momentos diferentes: al inicio, a la mitad y al final del año escolar. Los resultados mostraron una fuerte estabilidad de las medidas de lectura, escritura y matemáticas a lo largo de los tres momentos de evaluación. Se analizaron efectos concurrentes y temporales, revelando influencias bidireccionales y resaltando el papel impactante de la lectura. La estabilidad del modelo fue evaluada mediante remuestreo, demostrando consistencia en un alto porcentaje de comparaciones configurales frente a restringidas, junto con un RMSEA inferior a 0.7. Se analizan las implicaciones educativas de estos hallazgos, destacando su relevancia para mejorar los procesos de aprendizaje en lectura, escritura y matemáticas, especialmente en relación con las interacciones entre estos tres dominios.

Palabras clave: diseño longitudinal de panel, lectura, escritura, matemáticas.

Introduction

One of the foremost challenges for schools is ensuring that students acquire essential skills crucial for knowledge acquisition, including proficiency in reading, writing, and numeracy. Failure to attain these foundational skills during primary school years poses challenges that adversely affect academic performance (Robinson, 2004). Proficiency in both the literacy and math domains across developmental stages not only strongly predicts individual achievement within each realm but also reveals mutually influential predictive relationships (Duncan et al., 2007; Hooper et al., 2010). Decades of research affirm the reliability and validity of Curriculum-Based Measurement (CBM), a brief, standardized measure assessing student performance within the natural environment. It is flexible and adaptable to the local curriculum (Codding et al., 2015). The development of indicators of basic early reading skills [Indicadores de Progreso de Aprendizaje en Lectura, IPAL] (Jiménez & Gutiérrez, 2019), indicators of basic early writing skills [Indicadores de Progreso de Aprendizaje en Escritura, IPAE] (Jiménez & Gil, 2019), and indicators of basic early math skills [Indicadores de Progreso de Aprendizaje en Matemáticas, IPAM] (Jiménez & de León, 2019) aimed to provide concise and easily administered assessments for evaluating essential early reading, writing, and numeracy proficiencies among first-grade students in the Spanish language.

Indicators of Basic Early Reading Skills

The process of learning to read is not straightforward, given the multitude of components involved in the development of reading proficiency. To facilitate the instruction and assessment of the most critical components in reading education, the National Institute of Child Health and Human Development (NICHD) convened a panel of reading experts known as the "National Reading Panel" (NRP). Their objective was to conduct a systematic review of the existing scientific literature (NRP, 2000). In 2000, NRP concluded its work by producing a report that defined the five essential components of learning to read. These components are now recognized as the "Five Big Ideas": vocabulary, phonemic awareness, alphabet knowledge, fluency, and comprehension. Even though this report was based on English research, studies in Spanish have shown that these components are also crucial for reading acquisition in a transparent language such as Spanish, characterized by consistent orthography and well-defined syllabic boundaries (Jiménez et al., 2010).

Indicators of Basic Early Writing Skills

Theoretical models of writing, such as the Simple View of Writing (Juel, 1988; Juel et al., 1986) and the Not So Simple View of Writing (Berninger & Winn, 2006), emphasize the role of transcription skills (i.e., handwriting or typing and spelling) in the early development of written text production. Transcription is a fundamental cognitive process in writing that enables the writer to translate internal language into external written symbols to express ideas through written language (using pencil, pen, or keyboard) (Berninger et al., 2002). Transcription skills can be particularly crucial for initiating and developing writing in primary school years. Therefore, the simple view of the writing model predicts that if children are slow or inaccurate in transcription (e.g., slow handwriting or poor typing and spelling), then the quality of their written compositions will be low, as all their cognitive resources of attention and memory are allocated to the act of transcribing and converting phonemes into graphemes. Numerous studies have examined the relationship between transcription skills (e.g., handwriting and spelling) and written composition (e.g., composition quality or fluency) (for a review, see Graham et al., 1997). It has been demonstrated that transcription ability predicts writing fluency and composition quality in young writers (Abbott et al., 2010; Jiménez & Hernández-Cabrera, 2019; Berninger et al., 2009; Graham et al., 1997; Juel, 1988; Juel et al., 1986). One plausible interpretation is that, typically, enhancing writers' fluency or accuracy in transcription skills allows them to have more cognitive resources that can be utilized in discourse construction.

Indicators of Early Basic Math Skills

In the context of math learning, particular emphasis has been placed in the last decade on understanding the impact of early number sense on later math performance. It is essential to note that the construct of early math is much broader than just number sense (Missall et al., 2012). Empirical evidence from numerous studies highlights the pivotal role of numerical sense in math learning (Geary, 2013; Kolkman et al., 2013). Number sense, a term originally denominated as such in English, refers to the ability to represent and manipulate numerical quantities and is biologically determined (Dehaene, 1997). However, defining numerical sense has sparked various debates within the scientific community. The National Mathematics Advisory Panel (NMAP, 2008) defines numerical sense as an evolving construct, distinguishing between an informally acquired numerical sense and that which is acquired formally. The former pertains to the ability to immediately identify the numerical value associated with small quantities, develop basic counting skills, approximately calculate the magnitude of small sets of objects, and solve simple numerical operations. A more advanced conception of numerical sense is one that children acquire through formal instruction, requiring an understanding of place value, how all numbers can be composed and decomposed, and the meaning of basic arithmetic operations of addition, subtraction, multiplication, and division. Several authors support this subdivision of the numerical sense, referring to an earlier numerical sense that children typically acquire informally (Ivrendi, 2011; Jordan & Levine, 2009) before entering the educational system, serving as a crucial prerequisite for subsequent math achievement (Gersten & Chard, 1999). The National Council of Teachers of Mathematics, in the Curriculum and Evaluation of Standards for School Mathematics (NCTM, 1989), identified five components that define number sense: "the meaning of numbers, connections between numbers, the magnitude of numbers, actions performed with numbers, and the contexts that give meaning to numbers and quantities" (pp. 39-40). Building upon the aforementioned considerations and recognizing the expansive nature of the numerical sense concept, this study seeks to operationalize this concept by examining the following skills: (1) numerical magnitudes, (2) numerical operations, (3) place value, (4) counting, and (5) the number line. These abilities have been previously identified as pertinent to number sense in antecedent studies (Jiménez & de León, 2017; de León et al., 2021).

The Current Study

There is a lack of understanding regarding the developmental trajectories of the relationships among reading, writing, and math over time. Traditional longitudinal analyses have tended to focus on investigating each domain independently, missing the opportunity to concurrently examine the crucial interrelations among these three areas as they evolve over time (Peralta et al., 2023). The relationship between reading and writing is posited to be reciprocal (Shanahan, 1984; Shanahan & Lomax, 1986). In other words, reading has an impact on writing, and vice versa. This reciprocal perspective is grounded in the understanding that while reading and writing are distinct processes, they are interrelated due to the sharing of common knowledge and skills (Fitzgerald & Shanahan, 2000). Consequently, the knowledge and skills acquired in one mode may be transferable to the other, as they form the foundational elements of both reading and writing processes. The support for the bidirectional view of the Reading-Writing Connection (R<>W) relies heavily on correlational and cross-panel evidence, as noted by Shanahan (2016). Path analysis (Shanahan & Lomax, 1986) revealed that a bidirectional model of the Reading-Writing Connection (R<>C) was a more suitable fit for the data from second- and fifth-grade students. Similarly, the model suggesting an influence from reading to writing (R-W) outperformed the one proposing an influence from writing to reading (W-R). Recently, Jouhar and Rupley (2021) conducted a systematic review providing evidence that supports the bidirectional view of R<>W. As suggested by Pinto et al. (2015), most studies focusing on reading and spelling have predominantly centered around the English language, yielding results that diverge notably from those observed in other languages, particularly in orthographically transparent contexts. Notably, disparities emerge in the evaluation of reading, such as accuracy versus fluency, and in the developmental trajectories of reading and spelling. These variations underscore two primary distinctions between English and orthographically transparent languages, which hold particular significance in the analysis of the relationship between reading and spelling. However, in a replication of Shanahan's study conducted by Jiménez et al. (2020) in a language with a transparent orthography, such as Spanish, it is evident that the R<>W model fits the data better than the R-W and W-R models among the three models. These findings closely parallel those observed in the English context. While the study indicates a connection between reading and writing, a notable limitation is that the authors were unable to draw conclusions about the developmental nature of these relationships. The cross-sectional design hinders our ability to explore growth trajectories and developmental connections between reading and writing. Consequently, longitudinal research is needed to elucidate how growth trajectories in reading and writing are interrelated over time.

Moreover, there is a longitudinal association between early literacy skills and early numeracy skills, and children facing challenges in one domain are significantly more likely to encounter difficulties in the other domain (Purpura et al., 2011). In the analysis of data from the nationally representative Early Childhood Longitudinal Study - Kindergarten Class of 2010-11 (Tourangeau et al., 2015), correlations of .73, .73, and .72 were identified for children's reading and math achievement in Grade K, 1, 2, and 3, respectively. Korpipää et al. (2017) assessed the reading and arithmetic skills of 1,335 Finnish children at the end of Grade 1 and demonstrated that literacy and numeracy exhibit covariation.

To our knowledge, studies in the Spanish language that have examined the relationships among the three primary academic domains of the curriculum, namely, reading, writing, and math, and their developmental trajectories in students who initiate these learning processes are lacking. While our study investigated fluency in both literacy and numeracy, rather than exploring this through developmental phases, we examined it over the course of the first year of primary education. Therefore, the present study was designed to address the following questions: Is there a relationship between reading, writing, and math in first-grade elementary school children, and if so, is the pattern of associations between these three basic skills bidirectional over time?

Method

Participants

A sample of 392 first graders (185 boys and 207 girls; age M = 80.0 months; SD = 5.22) participated in this study. The participants were drawn from 20 state and 7 private schools located in Panama. The exclusion criteria were applied, and children with special educational needs, including those with sensory, acquired neurological, or other traditionally used exclusionary criteria for learning disabilities, were not included in the study.

Instruments

Curriculum-Based Measures

The CBMs used in this study include three equivalent alternate forms (A, B and C), which are administered at the beginning, middle, and end of the school year.

Indicators of Basic Early Reading Skills (IPAL) (Jiménez & Gutiérrez, 2019). The IPAL is administered individually and is composed of the following tasks:

- ***Letter Naming Fluency*** (LNF): Identify as many uppercase and lowercase letters as possible in one minute. The raw score was the number of correctly named letters (ICC = .99, $p < .001$).
- ***Letter Sound Fluency*** (LSF): Identify letter–sound correspondence in one minute (i.e., phonics). The raw score was the number of correctly identified letter sounds (ICC = .99, $p < .001$).
- ***Letter sound fluency*** *(LSF).* This task is presented on the same sheet as the former, but students have to identify letter-sound correspondence as quickly as possible in one minute. The raw score was the number of letter sounds correctly identified within the minute (ICC = .99, $p < .001$).
- ***Phonemic Awareness Fluency*** (PA): Segment nonsense words into phonemes in one minute. The raw score was the number of correctly identified phonemes (ICCr = 0.99, $p < .001$).
- ***Concepts about Print*** (CP): Answer six questions assessing basic knowledge of print books (i.e., the orientation of the book, directionality, awareness that the story is developed in the written, knowledge of terms related to reading, punctuation, and exclamation marks). For the untimed task, the raw score was the number of correctly answered questions (ICC = .98, $p < .001$).
- ***Nonsense Words Fluency*** (NWF): Read as many nonsense words as possible in one minute. The raw score was the number of correctly read nonsense words (ICC = .98, $p < .001$).
- ***Maze Sentences*** (MS): Identify the correct target word in 20 maze sentences with multiple-choice alternatives within 5 minutes. The raw score was the number of correctly identified targets (ICC = .99, $p < .001$).
- ***Oral Reading Fluency*** (ORF): Read aloud a short text with speed and accuracy. The raw score was the number of correctly identified targets within one minute (ICC = .96, $p < .001$).

In a recent study, the construct validity and longitudinal factorial invariance of the IPAL were analyzed in first-grade elementary students. The study demonstrated that the underlying structure of the IPAL is elucidated by observable indicators, including alphabetical knowledge, phonological awareness, oral fluency, comprehension, print awareness, and pseudoword reading. The research showed that this unidimensional factorial structure remained consistent across the three parallel forms administered at the beginning, middle, and end of the school year, indicating measurement equivalence over time (Gutiérrez, 2019; Gutiérrez et al., 2021). In addition, Gutiérrez et al. (2021) analyzed students' learning growth using hierarchical linear models. The results indicated that the majority of CBMs demonstrated adequate reliability and validity throughout the first grade, effectively capturing students' growth. More recently, in a study involving Colombian students of the same grade, Villadiego et al. (2024) reported that the latent variable of reading was also explained by the same observable indicators at the three time points during the school year.

Indicators of Basic Early Writing Skills (IPAE) (Jiménez & Gil, 2019). The IPAE is administered in a group and is composed of the following tasks:

- ***Allographs*** (A): Students write uppercase letters in lowercase within one minute. The raw score was the count of correctly written letters (ICC = .98, $p < .001$).
- ***Dictated words with arbitrary spelling*** (DWAS): Students write 17 familiar words with arbitrary spellings dictated by the examiner (b/v, e.g., boca/velero [mouth/Sailboat]; h, e.g., hora [hour]); j/g, e.g., jirafa/gitana [giraffe/gypsy]; ll, e.g., llave [key]); qu/c, e.g., pequeña/camisa [small/shirt]; and z/c, e.g., zapato/cine [shoe/cinema]). The raw score was the count of correctly written words (Cronbach's α = .78 - .83; ICC= .86, $p < .001$).
- ***Dictated words with rule-based spelling*** (DWRBS): Students write 20 words dictated by the examiner following specific spelling rules. The spelling criteria used were *"m"* before *p* and *b* (e.g., Tambor [drum]) and *"br"* and *"bl"* with *b* (*e.g.,* Blusa [Blouse]). The raw score was the count of words written correctly following the rules (Cronbach's α = .83 - .91; ICC= .93, $p < .001$).
- ***Dictated nonsense words*** (DNW): Students write 20 nonsense words dictated by the examiner. The raw score was the count of words with correct graphic representation of sounds (Cronbach's α = .89 - .92; ICC= .94, $p < .001$).
- ***Dictated sentences*** (DS): Students write a sentence dictated by the examiner containing words with arbitrary and rule-based spelling. The raw score was the count of correctly spelled words (ICC= .97, $p < .001$).

A study conducted by Jiménez & García (2023) demonstrated that within the IPAE, a latent factor related to transcription ability (i.e., handwriting fluency and spelling) underlies each of the observable indicators (i.e., allographs, dictation of words with arbitrary spelling, dictation of words with rule-based spelling, dictation of pseudowords, and dictation of sentences) at each measurement point (i.e., the beginning, middle, and end of the school year). Furthermore, the longitudinal factorial invariance of the three IPAE measures was shown in samples of first-grade elementary ***school*** students.

Indicators of Basic Early Math Skills (IPAM) (Jiménez & de León, 2019). The IPAM is a group-administered measure composed of five tasks lasting 2 minutes each, and the raw score for all tasks is the number of correct answers:

- ***Quantity Discrimination*** (QD): Students compare 64 pairs of numbers (1-99) and circle the larger one for a raw score (e.g., 34-15).
- ***Single-digit Computation*** (SC): With 45 mixed addition and subtraction problems (1-9) (e.g., 3 + 1), students solve as many problems as possible within the allotted time.
- ***Multidigit Computation*** (SC): This method is similar to SC but with numbers ranging from 1 to 99 (e.g., 28 + 12).
- ***Missing Number*** (MN): Students identify the missing number in 45 series and write it in the blank (e.g., 4, __, 6).
- ***Place Value*** (PV): Involves 45 figures based on the base-10 block structure (1-99), requiring students to identify and write the correct number.

Previous studies, conducted by de León et al. (2021) and de León et al. (2022), have validated the IPAM in a local, Spanish-speaking context, specifically among students in the 1st and 2nd grades of elementary school. In both studies, the latent factor of number sense, as elucidated by the indicators of quantitative discrimination, single-digit computation, multidigit computation, missing number, and place value, was reaffirmed. In the study by de León et al. (2022), longitudinal measurement invariance was explored and confirmed, demonstrating that the measurement model remained stable across the three measurement time points—namely, at the beginning, middle, and end of the school year.

Procedure

The implementation of this empirical study involved the approval of the Program for Improving Efficiency and Quality in the Education Sector PN-L1143; 4357/OC-PN, developed by the Ministry of Education of Panama, which includes within its strategic lines "Technical Support for the training of facilitators and review of educational resources. Contractual for External Products and Services (PEC)." Its general purpose is to offer specialized training that facilitates the detection, identification, and early intervention of students who may be at risk of presenting learning disabilities (LDs) in reading, writing, and/or math. First, a review and adaptation to the Panamanian Spanish modality of the IPAL, IPAE, and IPAM were carried out by a technical committee from the Ministry of Education of Panama (MEDUCA), supervised by the research group *Dificultades de Aprendizaje, Psicolingüística y Nuevas Tecnologías* (DEAP&NT) from the Universidad de La Laguna. A total of 20 supervisors from MEDUCA received training for the administration of universal screening tests. Two face-to-face training workshops, lasting one week, were held before the tests were administered at the beginning, middle, and end of the school year.

Data analysis

In this study, a data-driven approach was adopted, employing a cross-lagged panel analysis (CLPA) design that integrates structural equation modelling (SEM) to investigate the dynamic interplay among reading, writing, and math skills. Cross-lagged panel analysis is a statistical approach designed to elucidate bidirectional relationships or directional impacts among variables across different time points. Cross-lagged panel models (CLPMs), alternatively known as cross-lagged path models and cross-lagged regression models, are constructed using panel data. This type of data consists of longitudinal observations, capturing each individual or data point at multiple instances throughout time (Kearney, 2017). Measures of these academic domains were collected at three distinct time points during the school year: the beginning, middle, and end. To ensure robustness in the estimation of relationships among variables, the statistical analysis was based on the variance-covariance matrix. Though the correlation matrix was calculated using the Pearson coefficient, the underlying analysis employed the variance-covariance matrix. This variance-covariance matrix is crucial for accurately assessing the strength and direction of relationships among variables, and it is presented in the descriptive table along with the standard deviations of each variable. The CLPA approach enabled us to explore directional relationships and reciprocal influences among reading, writing, and math over time. SEM facilitated the examination of latent variables representing these academic skills, offering a comprehensive understanding of their dynamic interactions throughout the academic year. Specifically, we evaluated the cross-lagged effects of reading, writing, and math at each time point, shedding light on temporal associations and potential predictive patterns. To gauge the goodness of fit, we employed fit indices such as the comparative fit index (CFI), Tucker–Lewis index (TLI), and root mean square error of approximation (RMSEA). Missing data were addressed using the full information maximum likelihood method, ensuring that the available data contributed to accurate parameter estimation. Rigorous testing instilled confidence in the validity of the proposed structural relationships and their interpretation.

Our comprehensive data analysis strategy, complemented by stability assessments and bootstrapping procedures, allowed us to uncover and validate dynamic relationships among reading, writing, and math skills in this longitudinal panel study. To assess model stability, a bootstrapping procedure was implemented, iteratively dividing a random sample of 150 participants into two artificial groups. Configural and restricted models were created and compared 200 times, resulting in a 90% nonsignificant ratio for configural vs. restricted comparisons.

Results

This section presents a detailed analysis of the study's findings, exploring the relationships between the latent variables of reading, writing, and math abilities. The longitudinal panel design tracked 392 first-grade students at three time points: at the beginning, middle, and end of the school year. Our focus is on the stability of these skills over time and their mutual influences. Through coefficients, we assess the strength and direction of these relationships, revealing how these fundamental academic abilities develop and interact in early primary education.

Table 1 shows descriptive statistics and correlations for all reading, writing, and math achievement measures.

Table 1

Means, standard deviations, and correlations

Variable	*M*	*SD*	1	2	3	4	5	6	7	8
1. Reading Beginning	20.07	13.84								
2. Reading Mid-Year	28.03	16.28	.70**							
3. Reading End-Year	44.35	21.58	.54**	.76**						
4. Math Beginning	13.56	10.12	.56**	.51**	.40**					
5. Math Mid-Year	21.10	10.33	.52**	.58**	.55**	.72**				
6. Math End-Year	29.21	14.43	.51**	.54**	.58**	.58**	.69**			
7. Writing Beginning	7.87	15.67	.33**	.38**	.40**	.11	.18**	.31**		
8. Writing Mid-Year	20.42	22.26	.50**	.64**	.61**	.33**	.42**	.49**	.70**	
9. Writing End-Year	35.15	25.14	.50**	.67**	.72**	.35**	.44**	.52**	.59**	.72**

Note: M and SD are used to represent the mean and standard deviation, respectively. * indicates p < .05. ** indicates p < .01.

The goodness-of-fit indices for the longitudinal panel design study revealed a well-fitting model, as indicated by the scaled chi-square statistic (χ^2 = 26.996, df = 15, *p* <.05). The scaled indices, including the normalized fit index (NFI = .987), non-normed fit index (NNFI = .980), comparative fit index (CFI = .991), and Tucker–Lewis Index (TLI = .980), all exceeded the recommended threshold of .95, suggesting a robust fit. The root mean square error of approximation (RMSEA) yielded a low value of 0.058, with a confidence interval ranging from .019 to .093. These results collectively affirm the overall goodness of fit and reliability of the longitudinal panel model.

Table 2 presents standardized beta weights for both autoregressive and cross-lag paths, along with correlations between the beginning indicators and mid-year and end-year residuals in the first-grade model. Figure 1 displays statistically significant cross-lag paths for each grade.

Table 2

Results of cross-lagged panel analyses for the first grade

Parameter Type	Coefficient (n =392)			β	SE
Autoregressive, β	Writing Beginning	→	Writing Mid-Year	0.71***	0.03
	Writing Mid-Year	→	Writing End-Year	0.71***	0.03
	Reading Beginning	→	Reading Mid-Year	0.71***	0.03
	Reading Mid-Year	→	Reading End-Year	0.71***	0.03
	Math Beginning	→	Math Mid-Year	0.71***	0.03
	Math Mid-Year	→	Math End-Year	0.71***	0.03
Cross-lag, β	Reading Beginning	→	Writing Mid-Year	0.03	0.10
	Math Beginning	→	Writing Mid-Year	0.12	0.10
	Writing Beginning	→	Reading Mid-Year	0.15***	0.04
	Math Beginning	→	Reading Mid-Year	0.27***	0.07
	Reading Beginning	→	Math Mid-Year	0.11***	0.03
	Reading Mid-Year	→	Writing End-Year	0.36***	0.08
	Math Mid-Year	→	Writing End-Year	0.10	0.10
	Writing Mid-Year	→	Reading End-Year	0.18***	0.03
	Math Mid-Year	→	Reading End-Year	0.31***	0.07
	Reading Mid-Year	→	Math End-Year	0.10*	0.05
	Writing Mid-Year	→	Math End-Year	0.13***	0.03
Non recurring	Reading Mid-Year	→	Writing Mid-Year	0.56***	0.08
Correlation, r	Reading Mid-Year	with	Math Mid-Year	0.06***	0.02
	Writing Mid-Year	with	Writing End-Year	0.24***	0.02
	Writing End-Year	with	Reading End-Year	0.25***	0.02
	Writing End-Year	with	Math End-Year	0.11*	0.01
	Reading End-Year	with	Math End-Year	0.28*	0.02

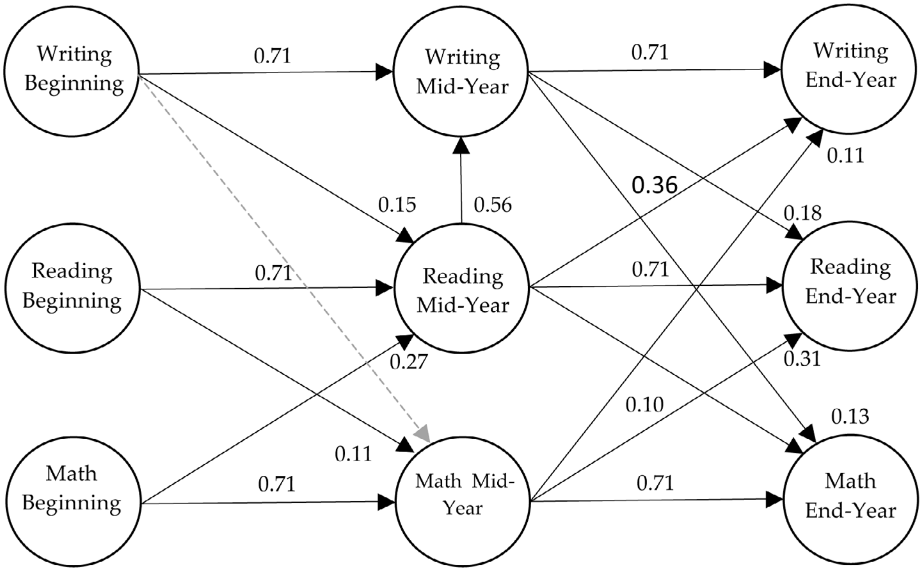

Figure 1. Model estimates from the cross-lagged panel model.

Note: Black solid lines are statistically significant at p <0.05. The grey dotted lines are nonsignificant at p >.05.

Autoregressive Analyses

Autoregressive analysis, with the constraint of equalizing coefficients (β = 0.71) across the three assessment points, highlights robust stability in reading, writing, and math skills during the first academic year. This constraint was imposed to facilitate the examination of cross-lagged changes and provides a foundation for evaluating the dynamic interplay among these domains over time.

Concurrent Relationships

In this longitudinal study, the initiation of writing modestly influenced midway reading (β = 0.15), the initiation of reading contributed to midway math (β = 0.11), midway reading significantly impacted concluding writing (β = 0.36), and midway math had a bidirectional relationship with concluding writing (β = 0.11). Midway reading strongly influences writing skills (β = 0.56), emphasizing its pivotal role, while writing has a discernible impact on math (β = 0.13).

Temporal Relationships

Temporal relationships revealed that the initiation of writing modestly contributed to midway reading (β = 0.15) and that the initiation of reading influenced midway math (β = 0.11). Initiation math significantly impacts midway reading (β = 0.27), midway reading predicts concluding math (β = 0.10), and midway reading has a lasting influence on concluding writing (β = 0.36). Midway math contributes to concluding writing (β = 0.11), and midway math predicts concluding reading (β = 0.31). These findings highlight dynamic and reciprocal relationships among skills over the course of the academic year.

Finally, to assess the stability of the estimated model, a random sample of size 150 was drawn and assigned to artificial group one, and the remaining 150 individuals who did not participate were assigned to group two. This procedure estimated a first configural model (free for both groups) and a restricted model (forced to be equal in both groups). This procedure was repeated 200 times. The number of configural vs. restricted comparisons that were nonsignificant was 90% (181 out of 200). In addition, 91.5% (183 out of 200) of the restricted models had an RMSEA less than 0.7.

Discussion

Several key findings have emerged in addressing the central question posed at the outset of this study—examining the relationship between reading, writing, and math skills in first-grade elementary school children and exploring the bidirectional patterns of associations over time. Our investigation into these fundamental academic domains aimed to uncover the intricate interplay among these skills during the critical early stages of education.

Stability of Reading, Writing and Math Parameters at Three Points in Time

According to the autoregressive hypothesis, a significant link exists between first-grade performance in a specific literacy skill and later performance in the same skills (Caravolas et al., 2001). This discovery substantiates prior research emphasizing the persistence of fundamental skills in reading, writing, and math during the early school years (Snowling & Melby-Lervåg, 2016). Overall, stability is evident in reading, writing, and math CBM constructs, showcasing consistent performance over time. These measurements taken at the three time points (at the beginning of the school year, at the midyear, and after the school year) had a beta coefficient of 0.71. This suggests relatively high stability in these skills over time between measurements, implying that a student's performance in each of these skills at the beginning is strongly related to their performance in mid-year and end-year. In Panama, primary education usually occurs at the age of 6. The formal instruction of literacy initiates within the primary school setting, adhering to a predefined curriculum mandated by national legislation. Panamian children typically commence their reading journey phonologically, with advancements observed in their capacity to read lexically, involving the direct retrieval of orthographic representations from memory, particularly throughout the initial two grades. Regarding math, the curriculum for first-grade children mandates that children develop foundational math skills. This includes but is not limited to acquiring a solid understanding of basic numerical concepts, such as counting, addition, and subtraction. Additionally, students are expected to grasp fundamental geometric shapes and spatial relationships. The curriculum aims to foster a conceptual understanding of mathematical principles, laying the groundwork for subsequent math proficiency.

Relationships between Reading, Writing and Math (within-time and cross-lagged correlations)

Our results provide robust evidence of a significant relationship between reading, writing, and math skills among first-grade students. Furthermore, our longitudinal analysis delved into the temporal dynamics of these relationships. The bidirectional patterns identified indicate that influences among reading, writing, and math are not unidirectional but rather reciprocal over the course of the school year. As indicated in the findings presented by Pinto et al. (2015), limited research has longitudinally delved into the correlation between reading and writing within a writing system characterized by transparency. Overall, the findings from these studies suggest a reciprocal and predictive relationship between reading and spelling (Cossu et al., 1995; Desimoni et al., 2012; Leppanen et al., 2006). Nevertheless, subsequent cross-lagged analyses conducted by Pinto et al. (2015) contend that spelling plays a pivotal role in the development of formal literacy, especially within transparent writing systems, as demonstrated in the context of first-grade Italian children. In the present study, at the beginning of the school year, the impact of writing skills on reading proficiency in the middle of the school year was measured at 0.15, signifying a moderate influence. This indicates that students exhibiting stronger writing skills at the beginning tended to exhibit improvements in reading midway. These findings align with Pinto et al.'s (2015) cross-lagged analyses, reinforcing the proposition that spelling's advancement during early stages serves as a foundational asset for subsequent reading skill acquisition. Additionally, Cossu (1999) demonstrated that in Italian first grade, spelling lags behind reading, in contrast to what occurs in English, where the two processes develop in a parallel manner. In the English language, Kim et al. (2018) analyzed the developmental trajectories of and the relation between reading and writing in students in grades 3-6 and found that the initial status of word reading predicted initial status and growth rate of spelling and that the growth rate of word reading predicted the growth rate of spelling. In contrast, spelling did not predict word reading.

Reading abilities have also been linked to math achievement (Paul et al., 2019). At the beginning of the school year, the influence of reading on math midway was 0.11. This coefficient is of low magnitude, suggesting that reading skills may have a slight influence on later math abilities. However, the influence of math at the beginning on reading midway was greater (0.27) than was the reverse influence, indicating that math skills at the beginning contribute to the improvement in reading midway. Utilizing a cross-lagged panel model, Duncan et al. (2007) conducted regressions in which later math achievement was regressed on prior math and reading achievement, along with control variables. Similarly, they performed regressions for subsequent reading achievement, regressing it on earlier reading and math achievements, as well as controls. Their findings indicated that math achievement exhibited a more robust predictive influence on later reading achievement than on later math achievement. According to a comprehensive analysis of six expansive longitudinal datasets, the average standardized effect size for math-to-observation estimates was 0.26. In contrast, the reading-to-math estimates averaged 0.10. In the present study, corresponding values of 0.27 and 0.11 were obtained, consistent with analogous findings. Reading proficiency has been shown to be associated with math attainment, with indications that its significance may vary across distinct math skills, such as the transcribing of numerical symbols. Numerous investigations have shown a correlation between competence in reading and writing numerical representations and proficiency in arithmetic computations (Geary et al., 2000). The capacity to transcode numeric symbols, involving the translation of numerical symbols between verbal and Arabic notations, assumes a pivotal role in school math. This reliance on the manipulation of symbolic numbers underscores the importance of this skill in math learning (De Smedt & Gilmore, 2011). Indeed, transcoding challenges have been linked to conditions such as dyscalculia and math learning disabilities (Mazzocco & Thompson, 2005). At the beginning of the school year, reading measurements influence writing and math at the end of the school year, with coefficients of 0.36 and 0.10, respectively. This finding suggested that reading skills are foundational and can influence the development of other skills. There is a strong influence (0.56) of midway reading on midway writing. Similarly, the influence of midyear writing on reading ability was observed, with a coefficient of 0.18 for the school year. These data suggest a bidirectional relationship between reading and writing, with both skills positively influencing each other. The influence of midyear math on writing and reading after the school year had coefficients of 0.11 and 0.31, respectively. These findings indicate that math skills also play a role in the development of reading and writing skills. Finally, midyear writing exhibits a low-magnitude coefficient (0.13) with math concluding the school year, indicating a slight relationship between these two skills. In summary, reading, writing, and math skills are interrelated over time, with strong individual stability for each skill. There are significant interactions among these skills, suggesting that strengthening one can positively influence the others.

Educational Implications

The study's educational implications underscore a bidirectional relationship between reading and writing, aligning with the cascade model theory and indicating that early decoding skills influence various literacy-related skills (Vellutino et al., 2007). This linkage is consistent with the notion that a solid foundation in decoding-comprehension contributes to the competent development of transcription skills. The interconnection between decoding-comprehension and number sense comprehension reinforces the conception that language-related skills and math skills are intertwined (Purpura et al., 2017). Our findings suggest that decoding-comprehension skills in early stages may influence the development of numeracy early skills, supporting the idea of a shared foundation for early academic learning (Purpura et al., 2015). The exploration of temporal relationships highlights the importance of early interventions, especially decoding-comprehension, which significantly influences transcription and number sense comprehension throughout the year. This emphasis on temporality aligns with research highlighting the effectiveness of early and targeted interventions in improving academic skills (Lonigan & Shanahan, 2010). The lasting influence of decoding-comprehension on transcription underscores the importance of considering reading skills in educational intervention planning (Suggate et al., 2018). This result supports the notion that an integrated approach to language skill development can have positive cascading impacts across multiple academic areas (Pardede, 2019). The interplay between numerical and transcription skills signals the need for pedagogical approaches that integrate language and math skills (LeFevre et al., 2010). These findings support proposals for an integrated curriculum that recognizes the inherent connection between language and math skills in the early years of education (National Research Council, 2009). Overall, our results offer a valuable contribution to the literature on early academic development. By integrating stable, bidirectional, and temporal relationships, our study sheds light on the complexity of interactions among latent variables. These findings inform educational practices by highlighting the importance of early and specific interventions that consider the interconnection of skills in students' learning processes during the first school year.

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