Early handwriting performance among Arabic kindergarten children: The effects of phonological awareness, orthographic knowledge, graphomotor skills, and fine-motor skills

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Abstract: This study aimed to delve into the under-explored domain of early handwriting performance among Arabic-speaking kindergarten children, focusing on the potential factors influencing early handwriting competency. The research encompassed 218 children from diverse socio-economic backgrounds in Israel. The underlying skills assessed were divided into linguistic skills (phonological awareness and orthographic knowledge) and graphomotor and fine-motor skills. Hierarchical regression analyses were utilized to evaluate the contributions of these skills. Results indicated that, within the Arabic orthographic context, orthographic knowledge stood out as a paramount contributor to early handwriting performance, more so than phonological awareness. Furthermore, graphomotor and fine motor skills significantly influenced letter-copying speed and legibility, but not the accuracy of letter-writing to dictation. In conclusion, while orthographic knowledge is paramount, the importance of graphomotor and fine motor skills for early handwriting performance in Arabic cannot be understated. The study suggests that a focused approach to these skills can lead to more effective interventions and teaching methodologies tailored for Arabic-speaking kindergarteners.

Keywords: Early handwriting, Phonologic awareness, Orthographic knowledge, Fine-motor skills, Graphomotor skills, Kindergarteners

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1. Introduction

In a kindergarten setting, a handwriting curriculum is still the primary mode of teaching, learning, and assessment in many contexts under the current educational system (Santangelo & Graham, 2016). Kindergarten is an essential period for developing foundational skills for early handwriting abilities (Ritchey, 2008) and a crucial time for acquiring the skills needed for successful writing (Kim et al., 2015). Handwriting is a necessary component that consistently demonstrates an association with writing performance (Graham & Santangelo, 2014) regarding text quality and quantity in kindergarten (Kent et al., 2014; Puranik & Al Otaiba, 2012), in first grade (Arrimada et al., 2019), and in second grade (Alves et al., 2016). However, relatively few researchers have investigated the performance in kindergarten of Arabic handwriting, which is characterized by orthographic complexity (Khoury-Metanis & Khateb, 2022). Therefore, the primary purpose of this study was to expand the current understanding of several potential factors that may contribute to early handwriting competency among Arabic-speaking children.

1.1 Early handwriting performance

The ability to write includes transcription and text-generation skills that contribute to writing ability (Simple View of Writing, Berninger et al., 2002). Text generation represents the ability to create ideas through language using higher-level skills. These include linguistic processes, such as elaborating ideas (semantic retrieval), organizing the construction of language (syntactical structure), and revision (Berninger et al., 2002). Transcription is the ability to put these ideas into text form. Conceptualizing transcription as a measurable construct is relatively straightforward and is most often measured through spelling and handwriting (Graham & Eslami, 2020). Handwriting is a perceptual-motor ability requiring the execution of precise hand movements guided by the visual input provided by the produced letter shapes (Afonso et al., 2020), whereas spelling and acquisition rely on understanding the correspondences between phonemes and graphemes (Treiman & Kessler, 2006; Ziegler & Goswami, 2005). According to connectionist models, spelling acquisition occurs as children become aware of the relationship between phonological input, orthographic output, and orthographic patterns and regularities (Treiman & Kessler, 2014) based on experiences and exposure.

Early handwriting can be assessed in different tasks, including copying letters from a model, writing all letters in alphabetic order, or writing letters from dictation (Ritchey, 2008; Graham et al., 2000). Research conducted with older children provides evidence of the importance of handwriting, including legibility, speed, and accuracy (Graham et al., 2000). These measures offer insight into a child's early writing abilities and are essential for understanding their later writing abilities. However, few studies included kindergarten children. Hence, in the current study, the children were asked to copy letters from a model and to spell individual sounds from dictation.

1.2 Linguistic skills

Linguistic skills comprise phonological awareness and orthographic knowledge in early handwriting performance. The literature reveals an ongoing debate about the relationship between phonological awareness and writing skills (Puranik & Lonigan, 2014; Molfese et al., 2006). The present study defines phonological awareness as one's ability to detect, manipulate, or analyze auditory speech sounds (Richardson & Nieminem, 2017). Share and Levin (1999) concluded that "phonology may well be a universal and inescapable feature of early reading and writing" (p.107). Research has shown a prominent role played by phonological awareness in higher achievement in early writing skills and inefficient performance at different stages of handwriting acquisition (Ray et al., 2021). The contribution of phonological awareness to writing performance was initially observed among children aged 3–5 years (Pazeto et al., 2017) and again among those 4–5 years old (Guo et al., 2018). Moreover, a strong correlation was found between phonological awareness and spelling acquisition among ages 5 and 6, based on tests in recognizing and naming the initial sound of words (Leppanen et al., 2006). The most significant independent contribution of phonological awareness consistently observed was as a descriptor of early writing performance achievements in grades 1, 2 (Abbott & Berninger, 1993), and grade 3 (Mendes & Barrera, 2017).

To date, relatively few studies have addressed the contribution of orthographic knowledge to early writing skills (Pritchard et al., 2021). Orthographic knowledge is defined as correctly representing language in written form (Apel et al., 2018). General knowledge of an orthographic system includes awareness of the consistencies or conventions by which letter combinations occur within a language (Ouelette & Sénéchal, 2008). This orthographic knowledge has most frequently been measured using a word-likeness task, usually structured as an orthographic choice task (Apel, 2011). Participants select either an accurate (correctly spelled) word or a distracting orthographic pattern. Orthographic knowledge has been shown to contribute to letter-writing skills in kindergarten (Puranik et al., 2011; Ouellette & Sénéchal, 2008) and in Arabic at the grade 1 level (Khoury-Metanis & Khateb, 2022). Additionally, orthographic knowledge significantly influences handwriting proficiency from grades 1 to 7 (Abbott et al., 2010). Research has indicated that orthographic expertise, or the ability to translate alphabet sounds into graphic symbols accurately and automatically, has a more direct effect on letter writing than fine motor skills (Abbott & Berninger, 1993; Costa et al., 2018; Puranik & Apel, 2010). Moreover, an intervention that emphasizes developing orthographic knowledge was associated with improvement in letter-writing skills among children aged 5.10–7 years (Mathwin et al., 2022). These studies suggest that orthographic knowledge mediates motor output for the letter-writing task (Abbott & Berninger, 1993).

1.3 Graphomotor and fine-motor skills in early handwriting performance

Handwriting is an element of transcription and, as such, is primarily perceived as a motor skill (McClelland & Cameron, 2019). Fine motor skills may be defined as the use of small muscles involved in movements that require the functioning of the extremities to manipulate objects (Gallahue & Ozmun, 2006). The performance of tasks may typically describe fine motor skills: manipulation of small objects and integration of visual-spatial organization (e.g., tracing, building with blocks), as well as tasks demanding manual dexterity and visual-motor control or eye-hand coordination (e.g., drawing with a pencil and copying designs), as demonstrations of graphomotor skills (Butler et al., 2019). Children's fine motor development has been linked to their reading and writing development in kindergarten (Oberer et al., 2017) and to literacy advantages in school (Cameron et al., 2016). Specific fine-motor dexterity skills, measured by motor accuracy tests (speed of sequential finger movements) and in-hand manipulation, have also been associated with handwriting skills among children in first grade (Cornhill & Case-Smith, 1996). Nevertheless, increasing evidence indicates that fine motor skills are particularly important for handwriting legibility (Daly et al., 2003).

Conversely, children with handwriting difficulties exhibit poor motor skills (Feder & Majnemer, 2007). According to a comprehensive systematic literature review by Ray et al. (2021), visual-motor skills reportedly played an essential role in letter-writing speed and accuracy. Handwriting outcomes were accelerated after visual-motor skills intervention for children aged 4–7 years (Bazyk et al., 2009). Visual-motor control has been associated with handwriting ability from kindergarten to fifth grade (Kaiser et al., 2009). The graphomotor skill of eye-hand coordination, as measured by the Invented Letter Test, predicted handwriting quality (Kaiser et al., 2009). Notably, automatic eye-hand coordination skills contributed to letter production and reproduction, better letter accuracy, and production in various languages from kindergarten to first grade (Mohamed & O'Brien, 2022). Thus, these skills warrant further attention as factors affecting handwriting performance (Ghanamah et al., 2023; Ray et al., 2021).

Additionally, a few studies revealed that among kindergarteners, higher fine-motor skill proficiency in handwriting is linked to better performance on writing assessments than their peers with lower proficiency (Daly et al., 2003). It was proposed that those who master the required fine motor skills may be better able to focus on higher-order concepts in writing (Cameron et al., 2012). However, little is known about graphomotor and fine-motor skills associated with kindergarten-level handwriting legibility and speed in Arabic. This language is particularly challenging to master.

1.4 A short overview of the orthographic characteristics of Arabic

Arabic is a Semitic language written from right to left. Arabic letters are unique in their visual similarities, changing allograph forms, and connectivity. The letters are grouped according to their basic form. Within each group, the letters are differentiated by the number and location of accompanying dots, which are an integral part of the letter and are placed below or above it (e.g., خ ح، ج، ب، ت، ث،; Abdelhadi et al., 2011; Asaad & Eviatar, 2013). The visual similarity increased letter confusion among Arabic-speaking kindergartners (Levin et al., 2008). Due to the complexity of Arabic orthography, children first learn the basic letter forms in kindergarten and later (usually in first grade) learn the variations of each letter (Taha & Khateb, 2013; Khateb et al., 2014). Last but not least, Arabic orthography varies; vowelized Arabic (including short vowels) is considered a transparent orthography, while non-vowelized Arabic is regarded as a deep orthography (Abu-Rabia, 2001). Hence, the unique features of the Arabic language may negatively affect writing performance in early primary school, compared to Hebrew, another Semitic language (Salameh-Matar et al., 2022).

1.5 Kindergarten literacy curriculum in Israel

The early literacy curriculum for Arabic refers to alphabetic skills, early handwriting, reading, oral language, communication skills, and book immersion. Teachers focus mainly on communication skills, letter knowledge, and phonological awareness (Hassunah-Arafat et al., 2021). Teaching Arabic in kindergarten employs various alphabetic exercises for phonological awareness and letter knowledge, along with book reading to expose children to the linguistic structures of Standard Arabic. Children learn to read short-vowelized words, which follow relatively consistent letter-sound conversion rules (Asadi et al., 2017). Writing instruction in kindergarten focuses exclusively on transcription. By the end of kindergarten, most students can name, sound, and form all Arabic letters. Students are also expected to leave kindergarten knowing phoneme-grapheme correspondence and can write syllables and simple words (Levin et al., 2008).

1.6 The present study

In view of the apparent of empirical research probing early handwriting performance among Arab kindergarten children, this study sought to clarify and identify underlying handwriting-related skills. Based on an earlier research review, we focused on several factors that may contribute to early handwriting performance. Research suggested that linguistic skills (phonological awareness and orthographic knowledge) (Leppanen et al., 2006; Mathwin et al., 2022; Pritchard et al., 2021; Richardson & Nieminem, 2017; Share & Levin, 1999), as well as graphomotor and fine-motor skills, (Ray et al., 2021) are related to early handwriting performance in several languages. It is hypothesized that linguistic skills best predict early handwriting performance (Bazyk et al., 2009; Ray et al., 2021), followed by graphomotor and fine-motor skills. Accordingly, this study will address the following questions:

1. To what extent do linguistic skills (phonological awareness and orthographic knowledge) predict early handwriting performance (letter-copying speed, legibility, and accuracy of letter-writing to dictation) after controlling for nonverbal intelligence among Arabic-speaking kindergarten children aged 5–6 years?
2. To what extent do graphomotor and fine-motor skills predict early handwriting performance (letter-copying speed, legibility, and accuracy of letter-writing to dictation) after controlling for nonverbal intelligence and linguistic skills among Arabic-speaking kindergarten children aged 5-6 years?

2. Method

2.1 Participants and procedures

A sample of 218 children, comprising 99 boys and 119 girls (age $M = 70.50$, $SD = 3.50$ months) participated in the study in the context of a large longitudinal study conducted at The Edmond J. Safra Brain Research Center for the Study of Learning Disabilities at the University of Haifa, and which included 73 kindergartens. The children in the present sub-sample were recruited from thirteen kindergartens that represented a variety of socioeconomic backgrounds in the north of Israel and around the Haifa area. All children included in the study: (a) had no neurological diseases and no physical disability that would affect their handwriting ability, and (b) were not receiving special education services. With the consent of the school principals, parents received a flyer with information about the purpose of the study and the study procedure (number of sessions, activities during the sessions); they were asked to provide a signed written consent form for their child's participation. The second author or one of five trained occupational therapists administered all study procedures individually in a spare room at the kindergarten during two sessions of about 20 minutes each. Testing sessions took place during the third trimester of the school year (May and June). Measurements assessed general ability using the Raven Colored Matrices (Raven, 2003); handwriting speed and legibility; linguistic skills (phonological awareness and orthographic knowledge); and graphomotor and fine-motor skills.

2.2 Tasks

Handwriting was assessed using two different tasks:
Copying letters. This task consisted of replicating seven Arabic letter forms from printed models to measure the legibility and speed of copying letters. The units of

the Arabic script are ordered according to visual similarity. One letter was chosen from each group of visually similar letters. Hence, this variety of allograph patterns and the production processes can be compared. which clearly demands different motor plans (ص، ع، و، ق، ج، ب، ش).

For legibility, the scoring was adapted to Arabic letters from the Scale of Children's Readiness In PrinTing (SCRIPT), developed for kindergarten children by Weil and Cunningham-Amundson (1994). The letters on the SCRIPT are scored as "correct" or "incorrect" according to specific criteria. Each letter must pass each criterion to be awarded one point. Failure on any individual criterion results in a score of zero for that letter (Marr et al., 2011). The maximum score for handwriting legibility was seven (Khoury-Metanis & Khateb, 2023). Inter-rater agreement was checked for 48 randomly selected participants, resulting in a raw score for this subsample of 93%, with a weighted Cohen's kappa of 0.81 and correlated at $r = 0.95$, $p < 0.001$. The handwriting speed was determined as the total time the child took to copy the seven letters.

Writing letters to dictation. In the dictation task, the children heard letter sounds, one at a time, and were asked to write the corresponding letters on a blank card, using the first two letters as practice trials. The examiner presented a sound and asked students to write the letter that makes that sound. The directions were standardized and were the following: "Now I am going to say a sound, and I want you to write the letter that makes that sound. Do your best. If you come to one you do not know, take your best guess, or we can skip it. Do you understand? OK, let us try one. Write the letter that makes the /m/ sound." The letter-sounds included in the task are /ء/, /ت/, /i/, /و//غ/, /ض/, /س/, /ذ/, /خ/, /ج/, and /ل/. The letters were chosen every third letter in Arabic alphabetic order. Responses were scored as correct if they represented the accurate spelling of the target letter sound. A two-point scale was used: (0) incorrect – no answer or wrong answer, (1) partial answer – writing a similar-looking letter from the same family or reversal answer, or (2) accurate answer. Cronbach's α across letters was .90.

Phonological awareness was assessed using the following two tasks:
First-sound isolation. Two versions of this task were developed for this study (Abu-Ahmad et al., 2018), and a composite score was calculated ($r = .48$, $p < .001$). The first version comprised words with a CCVC syllabic structure, and the second included words with a CVC syllabic structure. The children were asked to repeat the target word and isolate the initial consonant. Example: /qu:l mra:y/ ("Say 'mirror.'") /bkilmet mra:y mnismaʕ bilʔawwal/ ("In the word 'mirror,' we first hear '_____'…"). Correct response: m/demi phoneme ʔem/. One example and four practice items were presented before the task started. The test included 12 items, with a maximum score of 12. Test-retest reliability was .60 and .82 for the first and second subtest, respectively.

Final-sound isolation. This task was developed for the current study (Abu-Ahmad et al., 2018) and was administered at the kindergarten. The children were asked to repeat the target word and isolate the final consonant. All target items were CVC words. Example: /qu:l dob/ ("Say 'bear.'") /bkilmet dob mnismaʕ bilʔaxer/ ("In the word 'bear,' at the end we hear '_____'…") Correct response: b/demi phoneme ʔeb. One example and four practice items were presented before the task started. The maximum score in the task was 12. Test-retest reliability was 0.94 and 0.86 for the first and second rounds, respectively.

Orthographic knowledge was assessed using three different tasks, as follows:
Word identification. This task comprised 12 items and was adapted to Arabic (Yasin & Shalhoub-Awwad, 2018) from a previous study by Van der Kooy-Hofland et al. (2012). The child was required to identify a word read aloud by the examiner from four written words. The word list comprised frequent words of increasing difficulty and number of syllables. Six items are highly familiar, and the other six are less familiar (based on the judgment of 16 different kindergarten teachers). One example is provided before the start of the test. The maximum score is 12. The test–retest reliability was 0.86.
Word likeness. This task was developed for this study. It measures the child's sensitivity to legal and illegal orthographic patterns in Arabic script. The task contained 40 items: 20 legal orthographic patterns and 20 illegal orthographic patterns consisting of numbers, Hebrew and English letters, and words with an inappropriate positional variant of a letter form (allography; ياتًا أَهـ קصْظافولُ). The child was asked to answer with "yes" or "no," whether the word is legal in Arabic. One example and two practice items were presented before the task started. The maximum score for the task is 40—the reliability of this test: Cronbach's α =0.81.
Delayed copying. This task measures a child's orthographic knowledge through visual-orthographic copying skills, combining visual-motor and visual-orthographic knowledge. This combined skill is also crucial in Chinese writing, which typically requires knowledge of the positions, structuring, and functions of the radicals within Chinese characters (McBride-Chang et al., 2011). One of the best methods for assessing visual-orthographic copying skills is delayed copying tasks (Anderson et al., 2013). For this purpose, children were asked to copy an unfamiliar word after seeing it briefly on a computer screen, requiring rapid encoding and retrieval of visual patterns. Based on a previous protocol (Pak et al., 2005), three experimental items followed one practice item. Each item followed the sequence of a ready-check screen, a fixation point, a target word, and a blank screen. In the ready-check screen, the test administrator asked the participants if they were ready to start the test. Once the participants indicated they were ready, the experimenter pressed a button, and a fixation point appeared on the screen for two seconds. Immediately

after that, a target word (font size 200) appeared on the screen for five seconds, followed by a blank screen. The participants were asked to write the target word on paper. Scores were given according to copied letters and the letters' position; bonus points were given if the first or last letter was correct. For example, the item عصفور / ʕusfu:r/ will get a maximum of five points for correct letters, five points for correct letter positions within the word, and two points for writing the first and the last letter correctly (maximum score for each word is 12). The maximum score for the entire task is 36. Test reliability was Cronbach's α =0.75.

Graphomotor and fine-motor skills were assessed using four different tasks:
The Invented letter task. Based on Adi-Japha et al. (2011), this graphomotor task consists of point-to-point planar movements that do not require memory load because the visual stimuli and guides to movement direction are available to the participants throughout the task. Children are asked to connect three encircled dots with lines to form an invented letter, with movement progressing from right to left (as in Arabic writing). The examiner explained the task to the children who practiced it online; they were then asked to complete the task as rapidly and accurately as possible on a sheet of A5 paper using an HB pencil. General encouragement was offered during their performance of the task ("You are doing fine," "Pay attention to the task," "Remember to be as quick and accurate as possible!"). The children completed one experimental block.

Each letter must pass each criterion to be awarded one point—failure on any criterion results in a score of zero for that letter. The line must touch the three circled dots for maximum accuracy points. Speed is measured by tracking total time from the beginning to the end of the experimental block. Thus, two scores result from the task: accuracy and speed. The final score for the task is based on accuracy and speed. Number of accurate items per minute.
Making dots in circle. In this dexterity subtest of the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2; Bruininks & Bruininks, 2005), the child holds the pencil in the preferred hand and makes one dot in each circle, in any order, in 15 seconds. A circle is incorrectly dotted if it has no dot or more than one dot. A dash is counted as one dot. Also, a dot or dash that is partially inside and partially outside of a circle counts as correct.
The Functional Dexterity Test (FDT; Tissue et al., 2017). This visuomotor-control test uses a pegboard with 16 round pegs arranged in a four-by-four matrix. A tripod pinch is used to turn over each peg and replace it in the pegboard in a standardized pattern. Before test administration, hand dominance is determined (the hand the child spontaneously uses to draw a circle with a pen). A practice trial was performed after test instructions were given. The second trial was timed using a stopwatch. If a peg was dropped, the timer was paused, the peg was returned to its original

position, and timing resumed when the child continued turning pegs. The overall time was measured.

Pure copying. This task assesses visual-spatial integration by copying unfamiliar characters with no prior cognitive or orthographic experience or knowledge—in this case, Chinese script. The task consisted of 5 items and was time-limited, with the children allotted 5 min to finish the task (McBride-Chang et al., 2011). The reliability of this test in the current study was determined as Cronbach's α =0.81. In order to check inter-rater agreement, 50 of the 218 completed assessments were randomly selected to be double-coded. The raw score of inter-rater agreement for this subsample was 92%, with a weighted Cohen's kappa of 0.79 and correlated at $r = 0.93$, $p < 0.001$.

2.3 Data analysis

The analyses were performed using the SPSS.27 program. Before commencing data analysis, we discarded any data outliers based on the standardized residual ($d > 3$) to minimize their disproportionate effect on the overall predictive ability of the model. This procedure is acceptable when carried out prior to analysis. Additionally, the dataset was inspected for normality and homoscedasticity of the residual distribution, including checking for outliers. Following the normality assumptions testing methods of Larson-Hall (2015), histograms and p-p plots were charted for each variable's values (Brown, 2006) of skewness (between − 1 and + 1) and kurtosis (ranging from − 1 to + 1) were found for all variables, which formed histograms with a normal distribution. After confirming the normality assumptions, multiple steps were taken for data analysis. First, we employed Benjamini-Hochberg correction to adjust for multiple comparisons in our correlation analysis. This adjustment was crucial due to the multiple tests conducted, especially in the correlation tables with numerous f comparisons, heightening the risk of Type I errors. The adjusted p-values, notably a significant value of 0.00075 in key analyses. Then we computed descriptive statistics and Pearson's correlations between all measures. Second, exploratory factor analysis was conducted to classify the measures as variables to be entered in each block. Third, we used three hierarchical regressions to examine the predictors of handwriting legibility, speed, and legibility in writing letters to dictation. Hierarchical regression analysis is a sequential investigation of the influence of multiple predictors, whereby the relative importance of a predictor is judged through incremental variance indicated by each predictor set (Petrocelli, 2003).

3. Results

3.1 Descriptive statistics and correlations

Descriptive statistics for the study measures are presented in Table 1. Table 2 displays the correlation analysis between all these measures (dependent and independent variables). In the adjusted analysis, accounting for multiple comparisons using Benjamini-Hochberg, we observed a statistically significant association, with a corrected p-value of 0.0007. This finding indicates a robust effect, remaining significant even after stringent correction for multiple testing. The analysis showed that correlations were generally significant but tended to be low and that moderate correlations were mainly found between the accuracy of letter writing to dictation task (i.e., spelling) and the orthographic knowledge tasks: word identification (r =.50), word likeness (r = .42), and delayed letter-copying (r = .41). Also, moderate correlations were found between word identification on the one hand, and word likeness (r =.43) and delayed letter-copying (r =.47) on the other.

Table 1. Deriptive statistics for all measures (N = 218)

Measures	M	SD	Range
Raven (Colored Matrices)	10.15	2.75	3-17
Handwriting			
Copying Letters, Legibility	4.20	1.64	1-7
Copying Letters, Speed	44.56	13.50	18-79
Writing Letters to Dictation (legibility)	12.86	3.19	1-20
Phonological awareness			
Initial Sound Isolation	8.96	3.21	1-12
Final Sound Isolation	7.81	3.64	1-12
Orthographic knowledge			
Word Identification	6.30	3.54	1-12
Word Likeness	26.84	5.10	14-40
Delayed Copying	12.21	8.18	1-40
Graphomotor and fine-motor skills			
Invented Letter Task	13.38	4.35	1.25-24.86
Making Dots in Circles	30.01	8.24	10-55
Functional Dexterity Test	38.53	7.70	24.50-72.00
Pure Copying	15.54	3.08	4-20

Measures	1	2	3	4	5	6	7	8	9	10	11	12	13
1- Raven (Colored Matrices)	1												
2- Copying Letters Legibility	0.21**	1											
3- Copying Letters Speed	-0.11	-0.29***	1										
4- Writing Letters to Dictation	0.20**	0.35***	-0.20**	1									
5- Initial Sound Isolation	0.15*	0.07	-0.21	0.21**	1								
6- Final Sound Isolation	0.08	0.01	-0.11	0.25**	0.31***	1							
7- Word Identification	0.13	0.27***	-0.37***	0.50***	0.29***	0.41***	1						
8- Word Likeness	0.02	0.19**	-0.24**	0.42***	0.24**	0.25**	0.43***	1					
9- Delayed Copying	0.26**	0.24**	-0.32***	0.41***	0.26***	0.13	0.47***	0.27**	1				
10- Invented Letter Task	0.09	0.29***	-0.34***	0.21**	-0.05	0.05	0.16*	0.08	0.14*	1			
11- Making Dots in Circles	0.13*	0.07	-0.38***	0.22**	0.12	0.18**	0.21**	0.15	0.19**	0.29***	1		
12- Functional Dexterity Test	-0.17*	-0.18**	-0.34***	-0.15*	0.04	-0.04	-0.24**	-0.05	-0.25**	-0.28***	-0.24**	1	
13- Pure Copying	0.35***	0.23**	-0.15	0.21**	0.02	0.16*	0.20**	0.00	0.27***	0.29***	0.16*	0.18**	1

Table 2. Correlations between all measures

Note: This table presents the correlation coefficients between the studied variables. Asterisks denote the level of significance where *p < 0.05, **p < 0.01, and ***p < 0.0007 after adjustment.

3.2 Exploratory factor analysis

This analysis aimed to classify the variables to be entered into the hierarchical regression models. The analysis examined the nine independent measures of phonological awareness, orthographic knowledge, and graphomotor and fine-motor skills. As shown in Table 3, this analysis showed that all variables were loaded into two factors: a linguistic factor, which included all phonologic awareness and orthographic measures, and a fine-motor factor, which included all fine-motor and graphomotor measures. The KMO value is 0.72 (> 0.5). It supports the sampling adequacy for factorability, as Kaiser (1974) suggested. Bartlett's test of sphericity reaches statistical significance ($p < 0.001$). It indicates that the correlation matrix is not an identity and supports the factor analysis. After Varimax orthogonal rotation, nine major components with eigenvalues more significant than one were extracted. The first factor explained 29.31% of the variance, with an eigenvalue of 2.63, and the second factor explained 16.65% of the variance, with an eigenvalue of 1.49.

Table 3. Factor Analysis: All independent variables

Measures	Factor I	Factor II
Word Likeness	0.732	
Initial Sound Isolation	0.694	
Word Identification	0.662	
Final Sound Isolation	0.642	
Delayed Copying	0.526	
Invented Letter Task		0.726
Functional Dexterity Test		-0.676
Pure Copying		0.605
Making Dots in Circles		0.533
Eigenvalue	2.63	1.49
% of variance	29.31	16.65

3.3 Hierarchical linear regression

Predicting handwriting legibility: The final hierarchical multiple regression model used letter-copying legibility as a dependent variable was significant [$R = 0.45$, $F(10, 206) = 5.21$, $p < .001$] and explained 20% of the variance in handwriting legibility. In the first model, the nonverbal ability (Raven Test score) explained 4% of the variance in handwriting legibility [$R = 0.32$, $F(1, 215) = 10.23$, $p < .025$]. In the second model, linguistic measures explained an additional 9% of the variance [$R = 0.37$, $F\Delta$ $(5, 210) = 4.47$, $p < .001$] beyond nonverbal ability, with word identification (β=0.22, p = 0.008) being the only significant predictor. In the third model, the four graphomotor and fine-motor measures were entered, which increased the explained variance by an additional 7% ($R = 0.45$, $F\Delta$ $(4, 206) = 4.18$, $p < .05$); with the invented letter task (β= 0.22, p = 0.001) and word identification (β= 0.18, p = 0.026) independently predicting handwriting legibility (see Table 4, left).

Predicting handwriting speed: In a similar analysis conducted for handwriting speed, the final model explained 32% of the variance (letter-copying) [$R = 0.56$, $F(10, 206) = 9.77$, $p < .001$]. The nonverbal ability in the first model explained 1% of the variance [$R = 0.11$, $F(1, 215) = 2.77$, $p = 0.097$]. Linguistic measures in the second model increased the explained variance by an additional 16% [$R = 0.41$, $F\Delta$ $(6, 210) = 8.1$, $p < .001$] beyond nonverbal ability, with word identification (β=- 0.26, $p = 0.002$) and delayed copying (β = - 0.18, $p = 0.017$) as significant predictors. Graphomotor and fine-motor measures in model 3 increased the explained variance by an additional 15% ($R = 0.56$, $F\Delta$ $(10, 206) = 11.34$, $p < .001$, with word identification (β= -0.18, p = 0.017), the invented letters task (β= -0.19, $p = 0.003$), the dots-in-circles task (β= -0.22, p = 0.000) and the Functional Dexterity Test (β= 0.16, p = 0.011) independently predicting speed.

Predicting the accuracy of writing letters from dictation: The final model explained 37% of the variance in this skill [$R = 0.61$, $F(10, 206) = 12$, $p < .001$]. Nonverbal ability in the first model explained 4% of the variance [$R = 0.20$, $F(1, 215) = 8$, $p = .005$]. Linguistic measures in the second model increased the explained variance by an additional 31% [$R = 0.60$, $F\Delta$ $(6, 210) = 20.27$, $p < .001$] beyond nonverbal ability, with all orthographic knowledge tasks – word identification (β=0.28, p = 0.000), word likeness (β=0.24, $p = 0.000$), and delayed copying (β=0.19, $p = 0.004$) significantly predicting dictated writing legibility. Finally, in the third model, the four graphomotor and fine-motor measures increased the explained variance by 2% ($R = 0.45$, $F\Delta$ $(4, 206) = 4.18$, $p < .05$), with word identification (β= 0.26, p = 0.000), word likeness (β= 0.24, p = 0.000), and delayed copying (β= 0.17, p = 0.013) independently predicting writing legibility.

Table 4. Hierarchical regression analysis predicting children's early handwriting performance (N =218)

		Handwriting Legibility			Handwriting Speed			Writing Letters to Dictation		
		ΔR^2	β	t	ΔR^2	β	t	ΔR^2	β	t
Model 1		0.04**			0.01			0.04**		
Step 1	Raven		.21	3.19**		-0.11	-1.66		.19	2.92**
Model 2		0.09**			0.16***			0.31***		
Step 1	Raven		0.17	2.56*		-0.03	-0.54		0.09	1.64
Step 2	Initial Sound Isolation		-0.03	-.0.47		0.03	0.39		-0.01	-0.05
	Final Sound Isolation		-0.12	-1.66		0.04	0.54		0.05	0.83
	Word Identification		0.22	2.67**		-0.26	-3.20**		0.27	3.82**
	Word Likeness		0.10	1.48		-0.09	-1.26		0.23	3.80**
	Delayed Copying		0.09	1.21		-0.18	-2.40*		0.19	2.87**
Model 3		0.07**			0.15***			0.02		
Step 1	Raven		0.13	1.92		0.007	0.10		0.07	1.15
Step 2	Initial Sound Isolation		0.018	0.25		-0.02	-0.42		0.01	0.21
	Final Sound Isolation		-0.13	-1.81		0.05	0.87		0.03	0.57
	Word Identification		0.18	2.23*		-0.18	-2.41**		0.25	3.54**
	Word Likeness		0.11	1.64		-0.07	-1.13		0.23	3.76**
	Delayed Copying		0.05	0.69		-0.11	-1.69		0.16	2.49*
Step 3	Invented Letter Task		0.22	3.27**		-0.19	-3.01**		0.09	1.54
	Making Dots in Circles		-0.07	-1.14		-0.22	-3.63**		0.05	0.85
	Functional Dexterity Test		-0.04	-0.58		0.16	2.57*		0.02	0.43
	Pure Copying		0.09	1.27		0.03	0.51		0.05	0.92
Total R^2		0.20***			0.32***			0.37***		

*Note: This table presents the correlation coefficients between the studied variables. Asterisks denote the level of significance where *p < 0.05, **p < 0.01, and ***p < 0.0007 after adjustment.*

4. Discussion

Early handwriting performance requires a variety of underlying skills. The primary goal of the present study was to examine how phonological awareness, orthographic knowledge, and fine-motor and graphomotor skills contribute to early handwriting performance (letter-writing speed and letter-writing legibility, including accuracy of writing letters from dictation) among Arabic-speaking students in kindergarten.

As the first step toward this goal, we classified the underlying skills according to two factors: linguistic skills (e.g., phonological awareness, orthographic knowledge) and graphomotor and fine-motor skills (e.g., invented letter task, making dots in circles, Functional Dexterity Test, and pure copying). As the second step, we conducted hierarchical regression analyses to evaluate the direct contributions of kindergarten-level linguistic, graphomotor, and fine-motor skills to early handwriting performance measures.

4.1 The contribution of phonological awareness

The three hierarchical regression analyses showed a significant contribution of linguistic skills to all handwriting performance measures. Our findings, however, showed that phonological awareness' contributions failed to reach significance for the three handwriting measures, suggesting that compared to other skills, phonological awareness may be less critical for early handwriting proficiency in the case of Arabic orthography (Caravolas, 2006).

Contrary to our findings, most studies showed that phonological awareness consistently emerged as the most important fundamental factor in the handwriting acquisition process: for example, in Portuguese among 5-year-old kindergarteners (Leon et al., 2019) and in English at 5–6 years (Leppanen et al., 2006; Puranik et al., 2011). One possible reason that can explain these discrepancies may be related to the variety of handwriting performance measures. While our study assessed handwriting performance through letter-copying and accuracy of writing letter from dictation, earlier studies primarily assessed handwriting performance through name-writing and writing words to dictation (Leppanen et al., 2006; Leon et al., 2019; Puranik et al., 2011). For that reason, phonological awareness probably provided no clues for the copying task since it involves letter representation and how to write it (Ritchey, 2008).

4.2 The contribution of orthographic knowledge

As predicted, our results indicated that the three orthographic knowledge skills (word identification, word likeness, and delayed letter copying) contributed best to the three handwriting performance measures. These results confirm previous studies which revealed that orthographic knowledge contributes to handwriting performance in kindergarten letter-writing tasks (Kim et al., 2011; Puranik et al., 2011; Ouellette & Sénéchal, 2008), and also modulates the processes involved in handwriting production (Abbott & Berninger, 1993). Notably, the word identification task was uniquely predictive for all handwriting performance.

Indeed, the orthographic identification task includes correctly representing language in written form (Apel et al., 2018), and it supplies knowledge of the consistencies or conventions with which letter combinations occur within a language (Ouelette & Senechal, 2008). However, the word likeness task predicted only the accuracy of writing letters to dictation. This task requires distinguishing between words and nonwords that look like actual words (Apel, 2011). A fluent recall (retrieval of letter form from memory) is needed to decide on legal and illegal letter forms. Similar requirements are needed to write letters from dictation accurately (Parush et al., 2010).

The delayed copying task was also found to predict only the accuracy of writing letters to dictation. This task requires visual-orthographic copying skills, the rapid encoding of orthographic knowledge, and the retrieval of visual patterns of unfamiliar Arabic words (McBride-Chang et al., 2011). The delayed copying task mainly focused on accurate writing of real characters, in which children need to employ visual-motor skills for integrating strokes into letter forms while also legibly placing them (Khoury-Metanis & Khateb, 2022). To this end, our study provided an initial construct of evidence regarding the importance of establishing orthographic knowledge and memory. This can provide accurate information to guide the visual-orthographic motor system in letter shaping according to stroke order and direction (Kandel & Perret, 2015) and execute the actions needed to generate correct alphabet-letter writing (Berninger et al., 2006).

4.3 The contribution of graphomotor and fine-motor skills

As predicted, the graphomotor and fine motor skills showed significant variance in explaining handwriting performance contributions to letter-copying speed and to some extent to legibility, but not accuracy of writing letters to dictation. Since handwriting is a part of transcription, primarily perceived as using motor skills (McClelland & Cameron, 2019), the study results verified the assumption that early graphomotor and fine-motor skills are significant predictors of letter-copying measures. Such measures rely on tracing letter formation designs (visual-spatial integration), the core requirement of graphomotor skills. However, the accuracy of writing letters to dictation relies on letter recognition and fluent recall, retrieving visual representations of the target letter. This is mainly a nonverbal cognitive function that involves orthographic memory; thus, its nature explains the lack of association with graphomotor and fine-motor skills (Graham & Weintraub, 1996).

Graphomotor and fine-motor skills as measures demonstrated various contributions to handwriting performance. The invented letter task contributed significantly to letter-copying speed and legibility. These findings align with a prior study among five- to eight-year-old children, which revealed that average accuracy in the invented letter task predicted handwriting legibility and was associated with handwriting speed (Julius et al., 2016). The invented letter task identification and movement direction (Roebers et al., 2014). Furthermore, the task's accuracy and speed measures require hand–eye coordination, another necessary skill for good handwriting (Kaiser et al., 2009). Therefore, the invented letter task showed significant contributions to letter-copying measures.

Making dots in circles revealed a significant contribution only to letter-copying speed. This finding aligns with past work showing its significant impact on handwriting skills among kindergarten children (Butler et al., 2019). The finding is plausible due to the task's association with fine motor performance, particularly the precise movements that significantly impact handwriting (Fuelscher et al., 2018). Added are contributions to eye-hand coordination skills and letter production in various languages from kindergarten to first grade (Mohamed & O'Brien, 2022).

The Functional Dexterity Test is a fine-dexterity measurement method that particularly examines hand manipulation. Our study showed the test, itself, contributed significantly to the letter-copying speed. This finding supports the literature, which agrees that specific fine-motor dexterity is related to handwriting performance (Daly et al., 2003; Frolek & Luze, 2014). Additional evidence backing our results is found in a study by Bazyk et al. (2009), which observed significant acceleration in handwriting outcomes after fine-motor skills and hand-function intervention for children aged 4–7 years. Furthermore, our findings support previous studies showing that children with poor in-hand manipulation skills had difficulty with handwriting performance (Daly et al., 2003; Cornhill & Case-Smith, 1996).

The pure copying task is a foreign Chinese script, which the children executed using basic copying skills. In this study, the pure copying task showed no direct contribution to letter-copying or accuracy of writing a letter from dictation, contrary to a study among kindergarten children in mainland China (Wang et al., 2014), which showed that copying an unfamiliar print was uniquely related to word-spelling. However, it is worth noting that copying unfamiliar scripts requires visual-spatial integration rather than orthographic knowledge. Our results align with Cho (2020), who indicated that copying unfamiliar prints in Vietnamese did not significantly contribute to word spelling among Korean kindergartners, even after considering children's age and cognitive linguistic skills, like phonological and orthographic awareness. The lack of influence of pure copying on Arabic handwriting performance may be due to features of the seven letters included in the study. As well as the lack of experience in copying and writing words to dictation tasks; the latter being characterized by connectivity that might place additional visual-perceptual motor demands on the handwriting performance measures, rather than the limited demand of copying separate letters.

4.4 Conclusions, and implications for future directions

The findings of this study added clear confirmation to the literature by addressing the relationship between handwriting performance in Arabic orthography and different underlying skills. The study highlights the unique role of orthographic knowledge in early stages of handwriting acquisition among Arabic-speaking children. Our results establish the significance of assessing letter-writing skills as an indicator of children's developing orthographic knowledge. Moreover, the findings suggest a need for considering intervention programs, to emphasize developing orthographic knowledge and thereby to accelerate early handwriting performance in letter-writing measures. The study suggests that in light of the unusual characteristics of the Arabic language, focusing on phonological awareness as the predominant handwriting performance measure may not lead to promoting the acquisition of handwriting proficiency in the kindergarten years.

Beyond the orthographic skills in line with past work, the goal of evaluating and enhancing graphomotor and fine-motor skills is a unique and important pathway to early handwriting performance. However, graphomotor skills contribute to handwriting copying speed and legibility, while functional and manual dexterity contribute only to copying speed. Given that the graphomotor and fine-motor skills are clearly aligned with developing early handwriting performance, future studies are needed for more evidence with which to direct future intervention, along with clinical implications.

Future work should consider placing a greater emphasis on other relevant factors not covered in this study, which may impact early handwriting performance, such as gender differences, executive functions, and vocabulary knowledge. Likewise, more studies are needed regarding cultural variances in phonological awareness measures (letter-sound fluency, elisions, and phoneme deletions), which are known to contribute to early handwriting performance.

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