





RESEARCH ARTICLE

# Development, validity and reliability of the systematic screening for handwriting difficulties tool [version 1; peer review: 2 approved with reservations]

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**V1** First published: 23 Apr 2024, 13:313  
<https://doi.org/10.12688/f1000research.149049.1>  
 Latest published: 23 Apr 2024, 13:313  
<https://doi.org/10.12688/f1000research.149049.1>

## Abstract

### Background

The purpose of this study was to develop an Arabic handwriting screening test and establish its psychometric properties.

### Methods

Handwriting quality was evaluated using seven criteria from the Systematic Screening for Handwriting Difficulties Arabic (SOS-ARB) and writing speed were measured by counting the number of letters produced in 5 minutes. Construct validity was evaluated using

## Open Peer Review

Approval Status  

	1	2
<b>version 1</b> 23 Apr 2024	 <a href="#">view</a>	 <a href="#">view</a>
1. <b>Linda Greta Dui</b> , Politecnico di Milano, Milan, Italy		
2. <b>Denise Lesley Franzsen</b> , University of Witwatersrand, Johannesburg, South Africa		
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hypothesis testing (learning disabilities, sex and age differences). Convergent validity was examined using data from 106 children with dysgraphia who were also administered the French version of the "Concise Assessment Methods of Children's Handwriting" (BHK). Intrarater, interrater, and test-retest reliability were established for total and item scores.

## Results

Handwriting test data were collected from 1274 children (6–10 years) in regular education, of whom 194 were diagnosed with Learning Disabilities (LD). The SOS-ARB scores differed between children with and without LD ( $F(1, 1273) = 330.90, p < .001, \eta^2 = 0.209$ ), males and females, and different age groups. In addition, significant differences in writing speed were shown between children with and without LD ( $F(1, 1273) = 60.26, p < .001, \eta^2 = 0.046$ ), between females and males ( $F(1, 1273) = 7.57, p = 0.01, \eta^2 = 0.006$ ), and between the different age groups ( $F(4, 1270) = 21.762, p < .001, \eta^2 = 0.065$ ). A correlation coefficient of 0.72 for the quality score between the SOS-ARB and BHK confirmed convergent validity. Intrarater and interrater reliability were excellent in terms of quality scores (ICC coefficients = 0.988 and 0.972, respectively) and letter speed (ICC coefficients = 0.993 and 0.990, respectively). The quality score and letter speed had excellent and good test-retest reliability (ICC co-efficient = 0.968 and 0.784, respectively).

## Conclusions

Results indicate that the SOS-ARB is a valid and reliable tool for scoring Arabic handwriting abilities in elementary school children.

## Keywords

Handwriting difficulties, dysgraphia, assessment tools, legibility, letter speed, children, reliability, validity

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**Competing interests:** No competing interests were disclosed.

**Grant information:** The author(s) declared that no grants were involved in supporting this work.

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**How to cite this article:** Farhat F, Ammar A, Kammoun MM *et al.* **Development, validity and reliability of the systematic screening for handwriting difficulties tool [version 1; peer review: 2 approved with reservations]** F1000Research 2024, **13**:313 <https://doi.org/10.12688/f1000research.149049.1>

**First published:** 23 Apr 2024, **13**:313 <https://doi.org/10.12688/f1000research.149049.1>

## Introduction

Handwriting is a fundamental skill for children to learn in elementary school and is indispensable for their contribution to the classroom environment.<sup>1</sup> In fact, in many countries, handwriting is the primary tool for knowledge transmission and student evaluation.<sup>2</sup> Certainly, different processing subskills, such as morphological awareness, phonological processing and orthographic knowledge, contribute to the development of writing abilities, and their importance remains across elementary school years.<sup>3</sup> Furthermore, cognitive and fine motor skills are both implicated in the complex writing acquisition process.<sup>4</sup> If fundamental skills, such as fine motor skills, are not assured, text writing can be decreased.<sup>5</sup>

Handwriting abilities in other languages, such as Chinese,<sup>6</sup> Dutch<sup>7</sup> and French,<sup>8</sup> have been investigated. Although several studies have examined Arabic writing, research on handwriting quality has received little attention.<sup>7</sup> Arabic orthography has a Semitic alphabetic writing structure that has complex and unique attributes.<sup>9</sup> Moreover, slow-writing children could have problems with rapid adoption of orthographic knowledge rather than a problem in writing speed.<sup>10</sup> Indeed, poor ortho-graphic knowledge is more often a larger constraint than motor skills are in children with handwriting difficulties. Nevertheless, specific Arabic orthography features negatively affect writing acquisition in this Semitic language.<sup>11</sup> Consequently, these ortho-graphic features constitute a supplementary visual load in word recognition and influence writing acquisition.<sup>12</sup>

In primary school, handwriting is critical to academic success.<sup>13</sup> Thus, not mastering this activity can create serious challenges for children during the primary phases of learning.<sup>14</sup> Previous studies have shown that handwriting problems, particularly the inability to automatically write legible letters at a suitable speed, may be the primary indication of inadequate development of composition skills.<sup>15</sup> Dysgraphia is characterized by poor handwriting quality and speed.<sup>16</sup> Handwriting difficulties have been found in children with neurodevelopmental disorders, such as dyslexia,<sup>17</sup> specific language impairment,<sup>18</sup> attention deficit hyperactivity disorder<sup>19</sup> and developmental coordination disorder.<sup>20,21</sup>

Handwriting is a major cause of problems in school-related skills. However, early remediation has been shown to reduce the critical implications of handwriting problems during school careers.<sup>22–25</sup> Occupational therapy frequently supports improvements in handwriting skills. Therefore, it is crucial to develop a language-adapted tool to find students with handwriting problems and develop adaptive strategies and interventions.<sup>26</sup> To evaluate students' handwriting performance, several handwriting evaluation methods have been developed<sup>27</sup>; examples include the Evaluation Tool of Children's Handwriting–Manuscript (ETCH-M),<sup>7</sup> the Minnesota Handwriting Assessment (MHA),<sup>28</sup> the Test of Handwriting Skills–Revised (THS-R),<sup>29</sup> the Print Tool,<sup>30</sup> the Detailed Assessment of Speed of Handwriting (DASH),<sup>27</sup> the Concise Evaluation Scale for Children's Handwriting (BHK) and the Systematic detection of writing problems (SOS-NL).<sup>31</sup>

The SOS-NL demonstrated high validity in identifying children with and without handwriting difficulties. The SOS-NL was developed to support educators and therapists in identifying children writing difficulties who require handwriting remediation. This screening tool consists of the seven most sensitive items from the BHK.<sup>32</sup> It is therefore much shorter and easier to score. The SOS measures handwriting legibility and speed. Legibility was assessed by evaluating letter formation, letter fluency, letter size, regularity of letter size, spacing between words, alignment, and joins (for cursive writing). Speed is evaluated as letters written within 5 minutes. The SOS is an easy-to-use test and requires only a blank page, pen and timer, making it feasible for use in daily practice.<sup>31</sup> SOS has been adapted in other languages<sup>33</sup> such as Dutch, Flemish, and German with Latin script but not yet to Arabic writing systems.

Arabic-written language have distinct traits and formats based on their origin and evolution.<sup>14</sup> The handwriting difficulties appear to be more severe, as Arabic letters are defined by their unique form and intricate multiple-stroke sequences and directions.<sup>34</sup> Therefore, words vary in terms of their levels of graphic complexity, demanding that high levels of fine graphomotor skills and motor control abilities are required to make the pen stroke trajectory.<sup>35</sup>

As a result of rapid growth of technology, handwriting evaluation has progressed from paper and pencil tasks to computerized assessments, which provide a more scientific and standardized handwriting evaluation. In fact, Falk et al.<sup>36</sup> established a computer-based Minnesota Handwriting Assessment to examine handwriting speed and quality. However, similar studies on Arabic handwriting are limited. Currently, no standardized tools have been used to evaluate children's Arabic handwriting performance, thus data on validity and reliability of outcomes are lacking.<sup>9</sup> To accommodate these problems an existing evaluation method, the SOS-NL was adapted, studied, and validated for the SOS-Arabic Handwriting Test (SOS-ARB).

The purpose of the present study was to examine the construct validity of the SOS-ARB in different ways. Hypothesis testing was used by comparing groups with expected lower scores and higher scores both on handwriting quality and

number of letters written. It was hypothesized that children with learning difficulties would score poorer than typically developing children, boys would score poorer than girls and younger children would score poorer than older children. Next, convergent validity was evaluated by comparing the results of the SOS-ARB score of a text written in Arabic to those on the BHK of a text written in French in a group of children with dysgraphia. Correlations between these results were expected to be moderate.

Lastly, we investigated whether the SOS-ARB is a reliable tool by means of intrarater, interrater and test-retest analyses in Arabic handwriting scripts.

## Methods

### Participants

The study examined children aged between 6 and 10 years whose native language was Arabic. The children were selected from 17 elementary schools. For this random sample, children were recruited from areas with different degrees of urbanization in Tunisia. In Tunisia, in cooperation with the medical school center, children with learning difficulties (LD) attend mainstream primary schools and receive extra hours of support per week from their teachers. A total of 1300 participants were included, including a random sample of 1096 children without LD and 204 children with LD. The exclusion criteria included mental retardation, sensory disability, physical disability, or severe trauma. Twenty-six children who did not meet the inclusion criteria were excluded from the study, leaving a total of 1274 children (1080 children without LD and 194 children with LD).

In addition, another 106 children with dysgraphia were selected who were diagnosed by the clinical observation of attending physicians and were selected from the medical school center to participate in this study. Dysgraphia was defined by a score at or below 29 on the French adaptation of the BHK.<sup>8</sup>

### Procedure

The protocol and study design were approved, on January 27, 2021, by the Ethical Committee of the University Hospital of Sfax, Tunisia (CPP SUD N° 0300/2021), in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). After a full explanation of the procedure and prior to testing, all the parents provided written consent and signed child assent forms.

### Development of the SOS-Arabic

To assure content validity, the SOS was adapted for Arabic use by a diverse group of handwriting experts. The group included neurodevelopmental pediatricians, physical therapists, occupational therapists, speech and language therapists, teachers and pedagogues. Individual members' comments and suggestions were collected. Based on these suggestions, the Arabic handwritten text has been revised.

### Data collection

The children were tested as a group in their classrooms. The examiners described procedures to the children. All the children (with and without LD) provided written Arabic text for 5 minutes. In addition, 106 children with dysgraphia provided Arabic and French text separated by one-hour rest.

To evaluate test-retest reliability, the Arabic text was copied twice by 226 children without LD and 117 children with LD, with an interval of two weeks. These writers were chosen randomly.

### Raters

The SOS-ARB and BHK were administered by three trained occupational therapists. These examiners received instruction sessions for 10 hours for both the BHK and SOS-ARB tests. Each examiner practiced scoring 10 copies with the SOS-ARB and 10 copies with the BHK, and ratings were discussed to limit differences and consistency before scoring the participants' evaluation.

### Measures

#### *The BHK*

The BHK test is a standardized norm-referenced instrument used in individual clinical settings and classical school settings. Handwriting quality was assessed using 13 dysgraphia-specific handwriting criteria. These criteria are evaluated on an ordinal scale of 0 to 5, with a high score suggesting poor handwriting. A child with an overall score greater than 28 (the 10th percentile) was classified as dysgraphic. The writing speed was calculated by counting the number of letters produced within five minutes, including letter corrections. The interrater reliability was between 0.82 and 0.93 for writing

speed and between 0.42 and 0.63 for writing quality.<sup>37</sup> The correlation between the BHK and the De Ajurlaguerra Dysgraphia Scale<sup>38</sup> is reported to be 0.78.<sup>37,39</sup>

### *The SOS*

The SOS is a normative test used to identify writing difficulties. It can be used for school-aged children (from the end of the first to the sixth grade) who have a certain level of handwriting proficiency.

The total number of letters written within five minutes was used to determine writing speed. Handwriting quality was scored on seven characteristics: letter form, writing fluency, connecting strokes, letter height, regularity of letter height, space between words and straightness. These SOS items were used for the SOS-ARB, with lower scores indicating better performance. An assessment with the SOS takes approximately 10 min. The validity and reliability of the tool were found to be good (ICC 0.66–0.88).<sup>40</sup> The international guidelines for DCD have recommended the SOS to detect writing problems in children with DCD.<sup>41,42</sup>

### *The SOS-ARB*

The SOS-ARB is based on item descriptions and scores of the SOS but uses a different text. The instructions and administration have not been changed. For the SOS-ARB, the text was constructed to be appropriate for children in terms of its content and linguistic level while considering the phonological, morphological, syntactic and semantic structure of the language. The first paragraph was selected with words and sentences written during the preschool period, after which the text became increasingly complex. The text includes 29 Arabic letters. The text used verbs, nouns, inflectional and derivational forms and terms requiring specific orthographic knowledge thus assuring that the content was appropriate to screen for handwriting problems in this age bracket.

The handwriting task was to replicate this standard text for 5 minutes (or at least the first five sentences for slow writers) on an unlined A4 piece of paper. The children were asked to copy the text as quickly and accurately as possible.

The first five sentences were used to assess handwriting quality based on the seven criteria of the SOS, in which 0 signifies the item's absence and 1 represents its presence. The total score could vary from 0 to 35 points, with a high score indicating poor handwriting quality. Writing speed was calculated as the number of characters (i.e., letters as well as punctuation marks) written per minute.

### Statistical analysis

The Kolmogorov–Smirnov test was used to determine the normality of the distribution of all the variables. The mean (M) and standard deviation (SD) were used to represent the data, while categorical variables are shown as the frequency and score. Univariate analysis of variance with 3 between subject factors (learning level, sex and age) was used to examine the effect on writing quality and speed. Pearson correlation coefficients were used to assess the convergent validity between the SOS-ARB and BHK scores.

For reliability, the scores between the two measurements were evaluated using the intraclass correlation coefficient (ICC) and the corresponding 95% confidence interval. To assess the intrarater, interrater, and test-retest reliability of the total quality score and writing speed (number of characters), we used the ICC (two-way mixed effects model, single measures). An ICC of 0.3-0.5 indicates lower reliability; 0.5-0.7 indicates moderate reliability; 0.7-0.9 indicates high reliability; and 0.9-1.0 indicates excellent reliability.<sup>43</sup> Kappa statistics were used to assess intrarater, interrater, and test-retest agreement for item scores. Kappa values range from -1 to +1, with the following categories: -1 for perfect disagreement, 0 for chance agreement, 0-0.2 for poor agreement, 0.21-0.4 for fair agreement, 0.41-0.60 for moderate agreement, 0.61-0.80 for good agreement, and 0.81-1 for very good agreement.<sup>44</sup>

The standard error of measurement (SEM) and the smallest detectable change (SDC) were calculated. The SEM was determined by dividing standard deviation of the difference by the square root of two Sd's. To calculate the SDC (95%), the standard deviation of the difference was multiplied by the 1.96. The systematic proportional bias was visually examined using Bland–Altman plots between the time points and limits of agreement (2 SDs). The significance level was set at  $p < 0.05$ . All the statistical analyses were performed using SPSS 28.

## Results

### Descriptive statistics and children's handwriting performance

The demographic data are shown in [Table 1](#). Children were classified by grade and age.

**Table 1. Demographic data of children with and without learning difficulties.**

Grade	Age range	Children without learning difficulties				Children with learning difficulties			
		Mean age (SD)	Number	Female	Male	Mean age (SD)	Number	Female	Male
1	<7	6.42 (0.28)	214	121	93	6.46 (0.24)	26	11	15
2	7–7.99	7.42 (0.29)	249	121	128	7.43 (0.28)	44	22	22
3	8–8.99	8.46 (0.29)	208	110	98	8.43 (0.27)	65	31	34
4	9–9.99	9.51 (0.28)	223	120	103	9.43 (0.29)	33	11	22
5	10–10.99	10.52 (0.29)	186	93	93	10.51 (0.29)	26	11	15
Total			1080	565	515		194	86	108

SD = Standard Deviation.

**Table 2. Mean (standard deviation) SOS-ARB quality score, letter speed for the different groups of children.**

Grade	Quality score <sup>a</sup>			Letters speed <sup>b</sup>		
	Total children	Female	Male	Total children	Female	Male
Children without learning difficulties						
1	9.37 (3.67)	9.16 (3.76)	9.65 (3.60)	109.41(44.11)	115.76 (51.04)	101.13 (31.37)
2	8.43 (3.55)	8.16 (3.71)	8.68 (3.38)	217.11 (205.47)	248.54 (287.85)	187.66 (48.37)
3	7.86 (3.93)	7.00 (3.40)	8.81 (4.28)	267.16 (76.36)	277.97 (79.99)	255.04 (70.51)
4	6.58 (3.59)	5.74 (3.20)	7.56 (3.77)	309.13 (86.74)	326.16 (88.87)	289.29 (80.13)
5	5.42 (3.57)	4.84 (3.32)	5.99 (3.73)	388.11 (294.19)	437.62 (401.92)	338.60 (86.83)
Children with learning difficulties						
1	15.54 (2.54)	15.19 (3.22)	15.80 (1.98)	101.62 (26.91)	110.46 (33.43)	95.14 (19.70)
2	13.59 (1.88)	13.37 (1.95)	13.82 (1.82)	141.07 (36.98)	146.87 (42.68)	135.28 (30.14)
3	12.36 (1.73)	12.39 (1.86)	12.33 (1.63)	156.31 (35.84)	164.17 (40.02)	149.15 (30.40)
4	11.67 (2.22)	11.91 (1.58)	11.55 (2.51)	166.64 (34.70)	187.10 (35.64)	156.41 (30.00)
5	10.73 (2.00)	10.10 (1.58)	11.20 (2.18)	218.27 (52.26)	243.64 (60.68)	199.67 (37.03)

<sup>a</sup>A high score corresponds to poor handwriting quality.

<sup>b</sup>Letter speed is the number of characters (letters as well as punctuation marks) produced in 5 min.

A total of 515 males (47.7%) and 565 females (52.3%) were without LD, while 108 males (55.7) and 86 females (44.3%) were with LD.

The main results concerning the handwriting performance of the children with and without LD in grades 1 to 5 are presented in [Table 2](#). [Table 2](#) shows the quality scores and letter speeds corresponding to age, sex, and group (with and without learning difficulties) based on the Arabic handwritten text results.

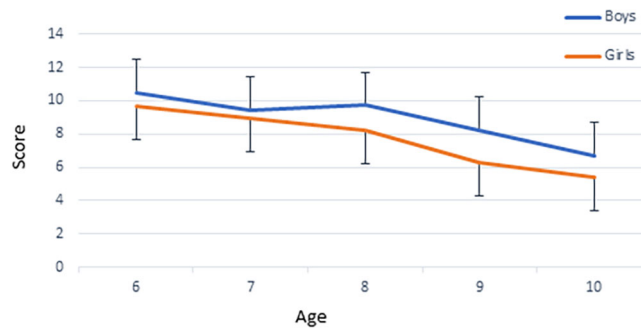
### Known group validity

**Handwriting quality scores:** The univariate analysis of variance results are summarized in [Table 3](#), which shows the differences according to learning level (NoLD/LD), age and sex. The analysis indicated significant differences in handwriting quality scores between children with and without LD ( $F(1, 1273) = 330.90, p < 0.001, \eta^2 = 0.209$ ). A significant main effect of sex ( $F(1, 1273) = 6.91, p < 0.01, \eta^2 = 0.005$ ) and age ( $F(4, 1270) = 23.04, p < 0.001$ ) was shown for the total scores. [Figure 1](#) illustrates the differences in handwriting quality between age groups for boys and girls. [Figure 2](#) shows the differences in age groups for children with and without LD, all in the hypothesized directions. As expected, the handwriting score on each subtest increased with age ([Figure 1](#)). The post hoc analysis of the quality handwriting score for the total children found that quality scores differ between Grade 1 and Grade 2. There was no improvement between Grade 2 and Grade 3, Grade 3 and Grade 4 or Grade 4 and Grade 5. Likewise, post hoc results showed an increase in writing quality from second to fourth grade and improvement from third to fifth grade ([Table 4](#)).

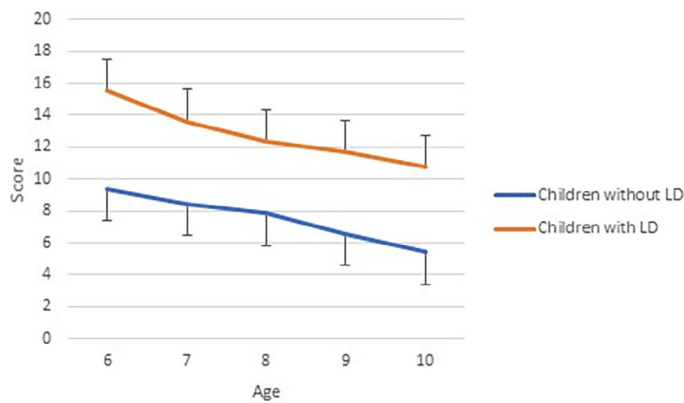
**Table 3.** Main and interaction effects test for total SOS-ARB quality score and letter speed.

	Quality score				Letters speed			
	F	p value	Partial $\eta^2$	Cohen's d	F	p value	Partial $\eta^2$	Cohen's d
Sex	6.91	<0.01	0.005	0.14	7.57	<0.01	0.006	0.15
Age	23.04	<0.001	0.068	0.54	21.62	<0.001	0.065	0.53
Group (TD/LD)	330.90	<0.001	0.209	1.03	60.26	<0.001	0.046	0.44
Sex * Age	0.15	0.959	0.001	0.06	0.54	0.705	0.002	0.09
Sex * Group (TD/LD)	1.96	0.161	0.002	0.09	0.85	0.356	0.001	0.06
Age * Group (TD/LD)	0.93	0.445	0.003	0.11	3.84	<0.01	0.012	0.22
Sex * Age * Group (TD/LD)	0.82	0.509	0.003	0.11	0.21	0.930	0.001	0.06

TD = Typically Developing, LD = Learning Difficulties, the level of significance was  $p < 0.05$ .



**Figure 1.** Quality scores for boys and girls.



**Figure 2.** Quality score for children with and without learning difficulties. LD = Learning Difficulties.

**Table 4.** Post hoc analysis for the age effect on the total SOS-ARB quality score in all children.

Grade	Grade	Mean difference	P value
Grade 1	Grade 2	0.831	0.147
	Grade 3	1.102	0.015
	Grade 4	2.799	<0.001
	Grade 5	3.963	<0.001

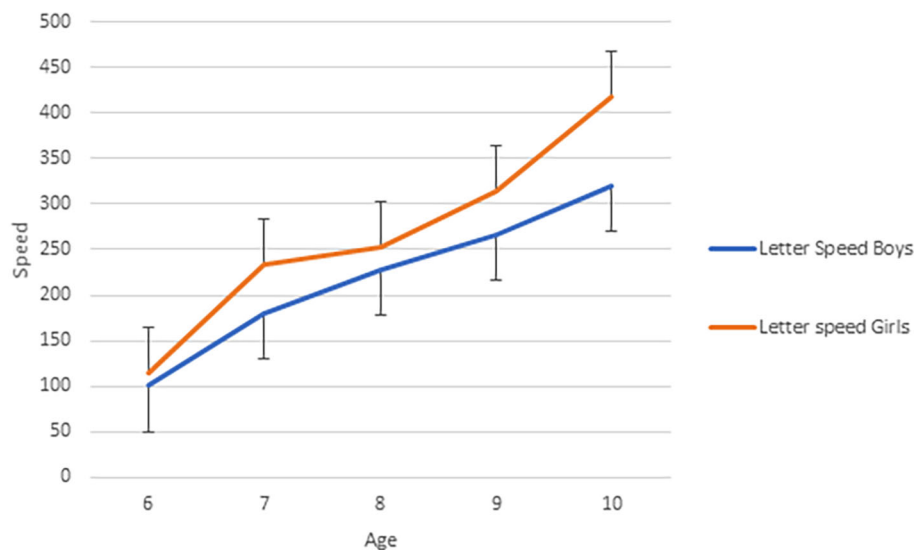
**Table 4.** *Continued*

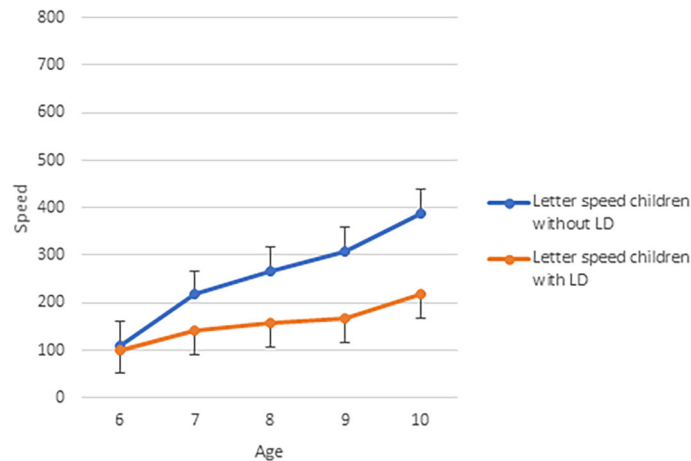
Grade	Grade	Mean difference	P value
Grade 2	Grade 1	-0.831	0.147
	Grade 3	0.271	1.000
	Grade 4	1.967	<0.001
	Grade 5	3.132	<0.001
Grade 3	Grade 1	-1.102	0.015
	Grade 2	-.271	1.000
	Grade 4	1.696	<0.001
	Grade 5	2.861	<0.001
Grade 4	Grade 1	-2.799	<0.001
	Grade 2	-1.967	<0.001
	Grade 3	-1.696	<0.001
	Grade 5	1.164	0.014
Grade 5	Grade 1	-3.963	<0.001
	Grade 2	-3.132	<0.001
	Grade 3	-2.861	<0.001
	Grade 4	-1.164	0.014

Boys had significantly poorer performance than girls but with small effect size ( $p = 0.01$  Cohen  $d = 0.14$ ).

The analysis also revealed that the difference in quality score between the NoLD and LD groups was large (partial  $\eta^2 = 0.21$ ; Cohen  $d = 1.03$ ). The probability that a randomly chosen Arabic writer with poor handwriting will have a higher score (worse) than a randomly chosen learner without poor handwriting was 77%, indicating good discriminative validity. Importantly, no significant first or second order interactions emerged.

*Handwriting speed scores:* Significant differences were found in letter speed between children with and without LD ( $F(1, 1273) = 60.26$ ,  $p < 0.001$ ,  $\eta^2 = 0.046$ ), between boys and girls ( $F(1, 1273) = 7.57$ ,  $p = 0.01$ ,  $\eta^2 = 0.006$ ), and between the different age groups ( $F(4, 1270) = 21.62$ ,  $p < 0.001$ ,  $\eta^2 = 0.065$ ). The effect sizes for the differences between age groups were moderate for letter speed. [Figure 3](#) shows that the letter speed increased, with age. Girls had significantly greater writing speeds (31 letters more in 5 minutes) than boys. [Figure 4](#) also shows the differences in letter speed

**Figure 3.** Letter speed scores for boys and girls.



**Figure 4. Letter speed score for children with and without learning difficulties.** LD = Learning Difficulties.

(mean difference = -98.99 letters,  $p < 0.001$ ) between children with and without LD. However, the interaction between age and learning level group was significant ( $F(4, 1270) = 3.84, p < 0.01$ ) indicating that there was a small difference in speed development (Partial  $\eta^2 = 0.003$ ; Table 3) between children with and without LD, which made the gap larger as children became older. No other first or second order interactions emerged.

#### Correlation between age, handwriting quality and speed score

A correlation was found between age, handwriting quality and speed score for children with LD (quality,  $r = -0.48$ ; speed,  $r = 0.61$ ) and without LD with (quality,  $r = -0.34$ ; speed,  $r = 0.47$ ).

#### Concurrent validity

The results of 105 children (61 males, 44 females) with writing problems between 8 and 10 years of age (mean age 8.97 years,  $SD = 0.81$ ) were used to compare the BHK and SOS-ARB scores. The Pearson correlation coefficient between total BHK and the SOS-ARB score was 0.72 ( $p < 0.001$ ) for the quality score.

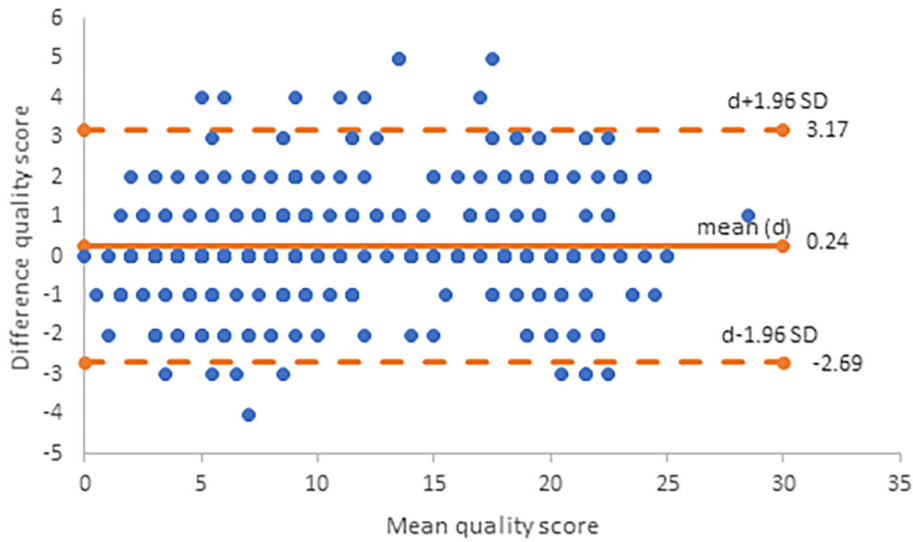
#### Reliability analysis

A total of 343 participants—226 children without LD and 117 children with LD—were selected from the different age groups for the reliability analysis. The intraclass correlation coefficient (ICC) and kappa coefficient statistics are reported in Table 5.

**Table 5. Kappa coefficients (for Items 1–7) and intraclass correlation coefficients (with confidence intervals of 95%) for the total SOS-ARB quality score and letter speed for intrarater, interrater and test-retest reliability.**

	Intrarater reliability	Interrater reliability	Test-retest reliability
Letter form	0.811	0.534	0.471
Fluency	0.752	0.650	0.512
Connection	0.840	0.741	0.634
Letter height	0.808	0.691	0.636
Regularity	0.819	0.593	0.466
Word space	0.772	0.708	0.662
Straightness	0.821	0.745	0.622
Quality score	0.988 (0.985–0.990)	0.972 (0.965–0.977)	0.968 (0.961–0.974)
Letters speed	0.993 (0.991–0.994)	0.990 (0.987–0.992)	0.784 (0.733–0.825)

All the coefficients were significant,  $p < 0.001$ .



**Figure 5. Bland-Altman plots and difference scores (Test 1-Test 2) for intrarater reliability.**

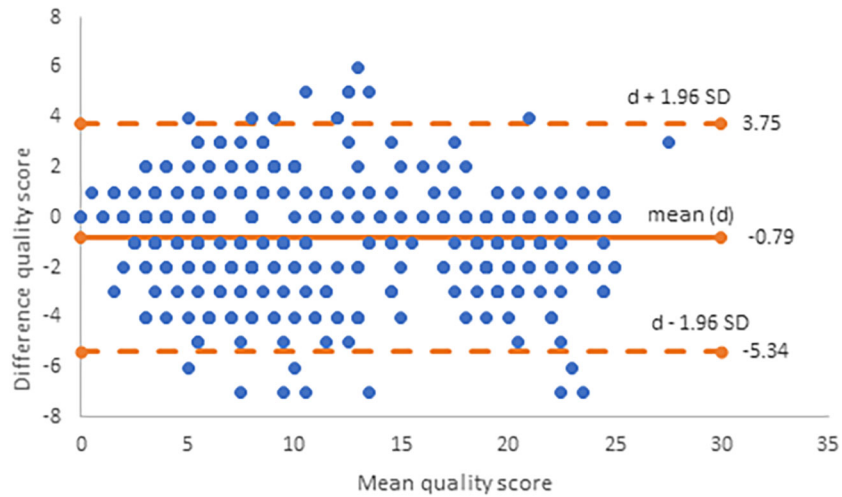
For intrarater reliability, the written text was evaluated a second time by the same rater after two weeks. The intrarater reliability was excellent for quality (ICC coefficient = 0.988 (0.985 – 0.990)) and letter speed (ICC coefficient = 0.993 (0.991 – 0.994)). The quality score per item (Kappa coefficients) demonstrated good to very good intrarater reliability (see Table 5). The Bland-Altman plots of the intrarater reliability quality score revealed that the systematic error for the mean value between the two test occasions was 0.24 points, and the limits of agreement ( $d \pm 1.96 SD$ ) were 3.17 and -2.69 points (see Figure 5). With respect to writing letter speed, the results indicated a systematic error of 0.72 letters for the mean value between the two test sessions, and the limits of agreement ( $d \pm 1.96 SD$ ) were 2.68 and -1.24 letters (Table 6).

For interrater reliability, the written text was evaluated a second time by another rater. The results are reported in Table 5. The ICCs indicated excellent interrater reliability for quality score and letter speed. The total Arabic handwriting quality score and writing speed were excellent (range from 0.965 to 0.992). The items of the quality score (with kappa coefficients ranging between 0.534 and 0.745) showed moderate to good interrater reliability (Table 5). The

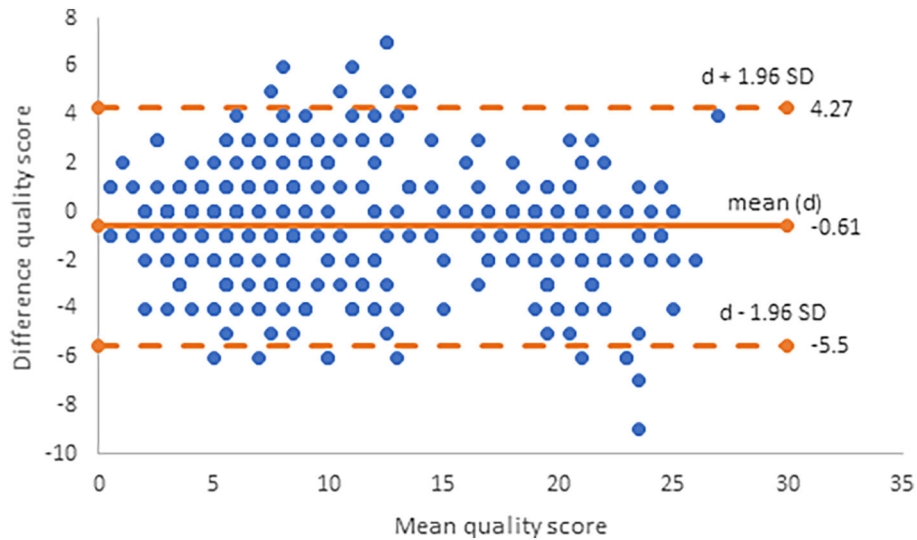
**Table 6. Reliability analysis and main outcome variables of the SOS-ARB total quality score and letter writing speed.**

	Mean test 1	Mean test 2	Grand mean	SD mean	Mean difference T1-T2	SD difference	SEM	SDC	t test	P value
SOS-ARB total quality score										
Intrarater Reliability	11.57	11.33	11.45	6.77	0.24	1.50	1,06	2.93	0.460	0.646
Interrater Reliability	11.57	12.36	11.96	6.93	-0.79	2.32	1,64	4.55	-1.467	0.143
Test-retest Reliability	11.57	12.18	11.87	7.00	-0.61	2.49	1.76	4.88	-1.118	0.264
Letter writing speed										
Intrarater Reliability	224.53	223.81	224.17	111.92	0.72	18.80	13,29	36.84	0.08	0.93
Interrater Reliability	224.53	218.83	221.50	111.03	5.32	26.26	18.57	51.48	0.66	0.50
Test-retest Reliability	224.53	221.11	222.63	94.71	3.04	87.69	62.01	171.87	0.42	0.66

SD = standard deviation, SEM = standard error of measurement; SDC = smallest detectable change.



**Figure 6. Bland–Altman plots and difference scores (Test 1–Test 2) for interrater reliability.**



**Figure 7. Bland–Altman plots and difference scores (Test 1–Test 2) for test-retest reliability.**

Bland–Altman plots for the interrater reliability quality score showed that the mean score had a systematic error of -0.79 points between the two tests, and the limits of agreement ( $d \pm 1.96$  SD) were 3.75 and -5.34 points (see Figure 6). Like-wise, the systematic error for the mean writing letter speed between the two test occasions was 5.32 points, and the limits of agreement ( $d \pm 1.96$  SD) were 7.28 and 3.36 letters (Table 6).

For test-retest reliability the selected group of children repeated the SOS-ARB after 2 weeks. As shown in Table 5, the ICC of the test-retest reliability coefficient was excellent for quality 0.968, and good for the writing speed (0.784). Test-retest reliability at the item level was moderate to good, with kappa coefficients ranging from 0.466 to 0.662. The Bland–Altman plots for the test-retest reliability quality score showed that the systematic error for the mean score between the two test occasions was -0.61 points, and the limits of agreement ( $d \pm 1.96$  SD) were 4.27 and -5.5 points (see Figure 7). In addition, the systematic error for the mean letter speed between the two test occasions was 3 letters, and the limits of agreement ( $d \pm 1.96$  SD) were 1 to 5 letters (Table 6).

### Discussion

Handwriting is an important and complex skill. A valid and reliable evaluation is required to identify children with handwriting difficulties. No standardized tool for handwriting assessment for Arabic is available. The aim of this study was to develop the SOS-Arabic handwriting test (SOS-ARB) and to establish aspects of validity and reliability.

To have content validity, the SOS-ARB must include the distinctive characteristics of the Arabic orthography. Indeed, much emphasis was placed on developing writing texts with content suitable for the children's grade level using a team of experts. All the 29 letters needed to be present in various forms (initial, middle or final) in the text. Similarly, the scoring system must reflect Arabic's distinctive characteristics, including letter construction and spatial organization. Our findings showed that the Arabic version of the SOS test is feasible in terms of instructions, assessment times, and different tasks. The SOS-ARB appears to be appropriate for evaluating children in grades one through five.

In this study, the letter speed was lower for children with LD than for those without LD. Likewise, children with LD had higher total quality scores, indicating poor quality writing, thus confirming discrimination properties of the SOS-ARB. These outcomes were in accordance with other findings in which the SOS was used to differentiate between students with and without handwriting difficulties.<sup>40</sup> Another study highlighted a significant difference in the BHK scale score between twenty-nine children with writing difficulties and twenty children without writing difficulties in the second and third grades.<sup>45</sup> Importantly, children with LD have a higher prevalence of reading disorders, and difficulties in reading could affect writing speed.<sup>46</sup>

Our results showed that comparisons between children with and without LD revealed that there was a significant interaction effect between age group and letter speed. Thus, handwriting development differs for children with LD. Children with LD may require special help at younger ages to avoid the widening of the gap. Our results showed that writing speed was more related to age than for quality. Moreover, a higher correlation was found between age and letter speed ( $r = 0.61$ ) for children with LD than for children without LD ( $r = 0.47$ ). However, writing speed can be the result of multiple factors, including motivation, attention and fatigue.<sup>47</sup>

Our findings showed that writing quality and letter speed improved from first to fifth grade. These findings are consistent with the development of handwriting abilities in other languages. Moreover, the evolution of handwriting performance was not linear. The present study showed that quality scores differ between Grade 1 and Grade 2. There was no improvement between Grade 2 and Grade 3, Grade 3 and Grade 4 or Grade 4 and Grade 5, demonstrating an important improvement in handwriting quality during the first year of learning followed by an absence of large evolution of the quality in the next Grades.<sup>48</sup> These results, however, differ from those of another study in English language which significant progress was shown between Grades 2 and 3, following a stable period throughout Grade 4, and a slight increase between Grades 5 and 6.<sup>49</sup> These variances could be attributed to curricular disparities in the scheduling and teaching of handwriting in different countries.<sup>50</sup> Similarly, our results revealed an increase in writing quality from second to fourth Grade and improvement from third to fifth Grade. These findings are consistent with previous research showing that children in fourth grade with an Arabic native language evaluate their handwriting measured performance better than children in second grade do.<sup>9</sup> Indeed, the age disparities observed in our study showed that the SOS-Arabic may be sensitive enough to developmental changes in handwriting during the early primary school years.

The current study showed that girls wrote more legibly than boys. These results were compatible with the findings of previous literature reviews.<sup>9</sup> This sex disparity could be explained by girls' earlier acquisition of motor control, particularly in activities demanding visual-motor coordination and tracing.<sup>51</sup> Moreover, in girls the left hemisphere matures faster. This could explain their superiority in the verbal domain necessary for reading and transcribing a text, which may also explain part of differences in copying a text.<sup>52</sup>

Moreover, we also found sex disparities in terms of letter speed. These conclusions were concordant with prior research findings. In this context, in a Dutch-speaking sample, findings showed an important disparity in favor of girls.<sup>53</sup> Furthermore, previous studies have shown significant sex differences in writing speed for Flemish<sup>40</sup> and Arabic<sup>45</sup> handwritten texts, whereas in other studies, no sex difference was noted in the Arabic handwriting performance.<sup>9</sup>

The findings also showed good concurrent validity of the SOS-ARB with the BHK test using French text. A correlation of 0.72 in quality scores between both tests confirmed convergent validity, which is consistent with the reported coefficient of 0.70 between the BHK and the test SOS<sup>40</sup> between the scores of both tests in Dutch.

The results of this study showed that the SOS-ARB has excellent intrarater, interrater and test-retest reliability for quality score and letter speed. The SOS-ARB is a reliable tool for measuring handwriting ability in children. The excellent interrater reliability of the items indicates that the interpretation and administration of the item scores are robust. The SOS-ARB is well standardized and provides stable outcomes over time. However, the interrater reliability was based on data from only three trained testers. Indeed, in this study, the reason for the excellent interrater reliability was that the raters received ten hours of training and practiced with 10 copies of children with and without LD.

The intrarater, interrater, and test-retest reliability of the items varied between moderate and very good. The moderate test-retest reliability observed for several item scores could be explained by fluctuations in handwriting style according to motivation, attention level, sense of achievement and goal of attainment in the writing task.<sup>54</sup> However, the children were asked to copy the text twice in 2 weeks. This could have decreased their motivation and attention in the retest without any concrete goal of attainment or sense of achievement.

The SOS-ARB was administered to children with and without handwriting difficulties and could provide an outcome measure for interventions aimed at improving handwriting skills. Previous research has shown that the orthographic properties of written language influence word length, allographic choice, letter complexity, and letter connections.<sup>55</sup> Moreover, handwriting legibility is influenced by children's copying strategy (whole words or letter-by-letter).<sup>34</sup> Subsequently, children could be trained to compose fluently connected handwriting, and spacing of letters and words. In fact, the interaction of the multiple unique aspects of the Arabic writing system may not limit the overall legibility of handwriting but rather favor flowing and continuous movements.

### Limitations

The analysis of the psychometric properties of the SOS-ARB yielded promising results; however, expanding the study to include other Arabic-speaking countries is needed in further studies. This study showed that the SOS-ARB can be useful for assessing Arabic handwriting. Additional investigations are needed to determine the predictive validity of the SOS-ARB score, collect reference norms in different Arabic-speaking countries and determine a clear cut-off point for poor handwriting ability or dysgraphia based on this tool.

In addition, Tunisian children are confronted with concurrent precocious graphic systems (Arabic and Latin writing), which include two distinct graphic structures that could provoke interference between the two different scripts and could have a substantial impact on the development of handwriting abilities. Hence, it is important to compare scripts used by children in different academic systems.

The SOS-Arabic could also be used in other groups of children known to have a high incidence of poor handwriting such as attention-deficit/hyperactivity disorder, learning disability, dyslexia or developmental coordination disorder. In this context, the SOS-ARB may also be an excellent tool for occupational therapists, in addition to educators. The SOS-ARB permits identifying children with difficulties in Arabic handwriting as starting point for handwriting intervention programs.

### Conclusion

This study showed that the SOS-ARB is a valid test for assessing handwriting ability in elementary school. During its development, it was important to consider the unique orthography of Arabic-speaking children. Data in other Arabic-speaking countries could be acquired and investigated to examine the generalizability of the SOS-ARB.

The SOS-ARB results obtained in the present study indicate excellent inter- and intrarater reliability and high test-retest reliability. A comparison with the BHK confirmed the convergent validity of the SOS-ARB quality writing score.

The structural validity and reliability of the SOS-ARB were the first steps in providing insight into the psychometric properties of the test, which will help with the identification of children with handwriting difficulties in Arabic-speaking countries.

### Ethics and consent

The protocol and study design were approved, on January 27, 2021, by the Ethical Committee of the University Hospital of Sfax, Tunisia (CPP SUD N° 0300/2021), in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

After a full explanation of the procedure and prior to testing, all the parents provided written consent and signed child assent forms.

### Data availability

#### Underlying data

Zenodo: Development, validity and reliability of the systematic screening for handwriting difficulties tool. <https://zenodo.org/doi/10.5281/zenodo.10880839>.<sup>56</sup>

This project contains the following underlying data:

1. Data of 1274 participants in the RCT titled Development, validity and reliability of the systematic screening for handwriting difficulties tool.
2. Data guidelines in the RCT titled Development, validity and reliability of the systematic screening for handwriting difficulties tool.

Data are available under the terms of the [Creative Commons Attribution 4.0 International license](#) (CC-BY 4.0).

## Acknowledgements

We acknowledge the support of parents, children, and management of the participating schools.

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# Open Peer Review

Current Peer Review Status: ? ?

Version 1

Reviewer Report 06 June 2024

<https://doi.org/10.5256/f1000research.163453.r270493>

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**Denise Lesley Franzsen**

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## Development, validity and reliability of the systematic screening for handwriting difficulties tool

- Is the work clearly and accurately presented and does it cite current literature?

Some revision to provide more clarity is required but relevant and recent literature is cited. Some texts are not recent but are appropriate to the study since handwriting assessments cited and used for development of the current assessment were published in the late 1990s and early 2000s.

- Is the study design appropriate and does the work have academic merit?

The study design covers all expected psychometric tests for confirming the validity and reliability of a newly developed assessment. Although there is an existing Arabic Handwriting Assessment (A-HAT) as indicated in the article this newly developed SOS-ARB is a shorter more easily administered assessment suit to screening and identifying dysgraphia amongst learners writing Arabic. The study has merit since it includes a large sample size and has considered all appropriate variables when assessing handwriting.

- Are sufficient details of methods and analysis provided to allow replication by others?

Some methods need clarity – see comments.

- If applicable, is the statistical analysis and its interpretation appropriate?

All is in line with test psychometrics with normal distribution of the data being established prior to analysis and both statistical significance and effect sizes reported. Interpretation is in line with that for psychometric properties of new assessments.

- Are all the source data underlying the results available to ensure full reproducibility?

Yes

- Are the conclusions drawn adequately supported by the results?

Yes

## Comments

In the introduction introduce the concept of the need for a quicker assessment that is easily

scored but do not indicate longer standardized Arabic version of handwriting assessments exist. Reword hypothesis – poorer does not seem appropriate here.

It is not clear if all children write in both Arabic and Latin scripts. Why was a second sample of 106 children (105 in results) with dysgraphia were selected (did the others write in Arabic only) – it would seem they completed two assessments for establishing concurrent validity between the BHK and SOS-ARB scores. Need to clarify that this was a separate sample who wrote in both Arabic and Latin text. Were selected appears twice in the sentence about these children.

To evaluate test-retest reliability, indicate children were chosen randomly from the existing school based sample of 1274 children.

None of the tables or figure indicate the sample size. When comparing scores for boys and girls did this include children with and without LD. Would be useful in identifying which sample the results represent.

It may not be necessary to include the SOS as a Measure – rather include this information under the development of the SOS-ARB or in the introduction.

Some statistical analysis gives interpretation of scores and methods of calculation. This is not done consistently so could be removed. Effect size (Cohen d) reported in the results is not mentioned in this section.

## References

1. Farhat F, Ammar A, Kammoun M, Mezghani N, et al.: Development, validity and reliability of the systematic screening for handwriting difficulties tool . *F1000Research*. 2024; **13**. [Publisher Full Text](#)

### **Is the work clearly and accurately presented and does it cite the current literature?**

Partly

### **Is the study design appropriate and is the work technically sound?**

Yes

### **Are sufficient details of methods and analysis provided to allow replication by others?**

Partly

### **If applicable, is the statistical analysis and its interpretation appropriate?**

Partly

### **Are all the source data underlying the results available to ensure full reproducibility?**

Yes

### **Are the conclusions drawn adequately supported by the results?**

Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Rehabilitation, Research methods, Occupational Therapy, Standardized assessments, Handwriting

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have**

**significant reservations, as outlined above.**

Reviewer Report 30 May 2024

<https://doi.org/10.5256/f1000research.163453.r270486>

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**Linda Greta Dui**

Politecnico di Milano, Milan, Lombardy, Italy

The study provides the validation of the adaptation to the Arabic language of a handwriting test. More details could be provided about the development of the test.

Reading the introduction, it is not fully clear if the main aim of the SOS questionnaire is to assess quality with or without accounting for orthography (pure dysgraphia or dysorthographia?) One of the hypotheses is that males would perform worse than girls. This is a fact in literature, but it should be introduced better.

In the Data Collection paragraph, it is not clear if your sample size was dimensioned using statistical power techniques, or which is the rationale behind the choice of your sample.

The Measures section would benefit from a common structure between paragraphs. E.g., scoring method, thresholds (these details are missing in the SOS paragraph).

BHK: it is not clear if a child is dysgraphic if scoring above 28 (as in the Measures paragraph) or below 29 (as in the Participants paragraph), or if it is a difference in the French adaptation.

SOS-ARB: please, report how many letters has the Arabic alphabet in the sentence "The text includes 29 Arabic letters .... OUT OF ??"

Statistical analysis

You are assuming that variables are normal, but please specify.

Are males and females matched in your sample?

Be consistent: NoLD or TD

**Is the work clearly and accurately presented and does it cite the current literature?**

Partly

**Is the study design appropriate and is the work technically sound?**

Partly

**Are sufficient details of methods and analysis provided to allow replication by others?**

Yes

**If applicable, is the statistical analysis and its interpretation appropriate?**

Yes

**Are all the source data underlying the results available to ensure full reproducibility?**

Yes

**Are the conclusions drawn adequately supported by the results?**

Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** machine learning an technological tools for specific learnin gisorders

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.**

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