HUMAN
TECHNOLOGY

ISSN: 1795-6889

www.humantechnology.jyu.fi

Volume 16(1), February 2020, 92–111

GRAPHOLEARN SI: DIGITAL LEARNING SUPPORT FOR READING DIFFICULTIES IN A TRANSPARENT ORTHOGRAPHY

Elisabeth Borleffs
Center for Language and Cognition
Groningen (CLCG)
and
School of Behavioral and Cognitive
Neurosciences (BCN)
University of Groningen
the Netherlands

Frans Zwarts
Center for Language and Cognition
Groningen (CLCG)
and
School of Behavioral and Cognitive
Neurosciences (BCN)
University of Groningen
the Netherlands

Ade R. Siregar
Department of Developmental Psychology
Faculty of Psychology
University of Sumatera Utara
Indonesia

Ben A. M. Maassen
Center for Language and Cognition
Groningen (CLCG)
and
School of Behavioral and Cognitive
Neurosciences (BCN)
University of Groningen
the Netherlands

Abstract: *Recognition of the importance of evidence-based technological tools that provide personalized learning opportunities is growing. This paper reports on a pilot study evaluating GraphoLearn for Standard Indonesian, a digital game environment that trains basic reading skills by extensive-but-playful exposure to grapheme–phoneme correspondences. The results obtained from 33 Indonesian first graders show that game progress was found to be a significant predictor of reading and decoding abilities both at the posttest and the 5-month follow-up assessment. Our results additionally indicated a significant interaction effect of game progress and letter–sound knowledge at posttest: Progress in the game was strongly related to reading and decoding fluency, but only for students with average to above-average pretest letter knowledge. To enable students with low letter knowledge at the outset to benefit fully from the game as well, we suggest extending the playing period to approximately 6 months to establish firmly letter knowledge and phonological awareness skills.*

Keywords: *technology-enhanced reading support, reading acquisition, digital learning environment, GraphoLearn, GraphoGame, Standard Indonesian.*

DOI: https:/doi.org/10.17011/ht/urn.202002242164

VERTAISARVIOITU
KOLLEGIALT GRANSKAD
PEER-REVIEWED
www.tsv.fi/tunnus

INTRODUCTION

Dyslexia is the most prevalent learning disability in modern societies, where the ability to read is an essential skill to be able to fully participate (Cortiella & Horowitz, 2014). Prevalence rates depend on the exact definitions and diagnostic criteria used. However, following a common definition in which the cutoff for reading achievement is set at 1.5 standard deviations below the mean for age, 7% of the general population can be identified as being dyslexic (Peterson & Pennington, 2015). Children with dyslexia face not only persisting problems with reading and spelling (Lyon, Shaywitz, & Shaywitz, 2003) but also negative effects on cognitive development, school motivation, well-being, and self-esteem (Lovio, Halttunen, Lyytinen, Näätänen, & Kujala, 2012). Within the field of learning difficulties, evidence-based technological tools that provide personalized learning opportunities increasingly are recognized as important (Beddington et al., 2008; Kyle, Kujala, Richardson, Lyytinen, & Goswami, 2013). If these tools are designed in such a way that progress depends on learning, struggling learners can be given more practice opportunities; such tools also create the possibility for individualized instruction and support.

In this paper, we discuss the results of an extended pilot study using GraphoLearn for Standard Indonesian (GraphoLearn SI), a digital learning environment that trains basic reading skills by extensive-but-playful exposure to grapheme–phoneme coupling. The development of effective language-specific reading acquisition programs and interventions such as GraphoLearn, which is based on thorough knowledge of orthographic features, can be of great value to any struggling reader. Even more so, such programs can benefit those students learning to read orthographies that have not yet been extensively studied, where the development of such tools can play an important role in preventing illiteracy or alleviating difficulties resulting from dyslexia.

GraphoLearn SI

Since its creation through collaboration between the University of Jyväskylä and the Niilo Mäki Institute in Finland, multiple language versions of GraphoLearn[1] have been developed that follow the same key principles, although adjusted to the specific language characteristics. An important characteristic of the training is its focus on the most functional sublexical units of the particular orthography being learned (Richardson & Lyytinen, 2014). For readers developing skills in transparent alphabetic orthographies with consistent grapheme–phoneme correspondences, such as the Standard Indonesian language (see the Standard Indonesian Orthography section for more details), the simplest and quickest way of learning to decode is to focus on exactly these connections (Holopainen, Ahonen, & Lyytinen, 2002; Landerl, 2000). Effectiveness studies evaluating GraphoLearn methods have, so far, shown promising results (e.g., Brem et al., 2010; Kyle et al., 2013; Saine, Lerkkanen, Ahonen, Tolvanen, & Lyytinen, 2010, 2011).

We designed GraphoLearn SI to support primarily young students whose SI reading skills appear to lag behind those of their peers at the elementary stages of formal reading instruction. In the game, the player moves his/her game character around on a randomly generated map in an attempt to reach a door that leads to the next game level. Along the way, the player passes fields that may contain an item (e.g., a funny hat for the game character to wear) or an exercise. The game's key exercises consist of both paced and unpaced multiple-choice trials in which the player needs to match an acoustic stimulus (a phoneme, syllable, or word) to the corresponding written representation on the screen. These reactive types of trials alternate with more active tasks in which the student constructs written words from smaller components to match the spoken target words. For example, the student hears the word *kamu* /kamu/ [you] and needs to construct the written word using two syllable blocks *ka* (/kɑ/) and *mu* (/mu/). Based on the performance in each particular trial, the content of the subsequent trials is automatically adapted to the student's level with the aim to offer sufficient challenges as well as opportunities for success (Richardson & Lyytinen, 2014).

Our research group developed two versions of GraphoLearn SI: The main design comprises 21 streams subdivided into 333 levels, whereas a compressed version offers the same 21 streams but in 177 levels. In line with other GraphoLearn studies (e.g., Kyle et al., 2013; Saine et al., 2010), the main design was developed to be played during five 10- to 15-minute sessions per week (see also Richardson & Lyytinen, 2014). The compressed version was created to accommodate school settings in which this preferred playing frequency would not be possible due to practical restrictions and where the complexity of the game content still needed to coincide with the level of the students' regular classroom reading instruction (see also Borleffs, 2018;[2] Borleffs et al., 2018). Details of the theoretical background, development, and design of GraphoLearn SI are described extensively in Borleffs et al. (2018). The Borleffs et al. (2018) paper additionally discusses the results of a pilot study among 69 typical and struggling beginning readers recruited from first-grade classes of an elementary school in the city of Medan (Sumatra, Indonesia). Students participating in the study published in 2018 played the compressed version of the game at a relatively low frequency: Between October and March 2015, the students attended, on average, nine GraphoLearn sessions of 15–20 minutes. The results of this pilot study were promising and indicated that the more the students with low pretest phonological skills were exposed to the game, the better their posttest performance on reading and decoding fluency. We, of course, still need more large-scale randomized controlled studies to explore further the effectiveness of our game designs.

In the present study, we tested a more intensive approach than we did in our 2018 pilot study by having 33 first-graders from a more rural area, that is, the outskirts of Medan, play the main design more frequently during a shorter period of time (see Methods section for more details; also see Borleffs, 2018). The aims of this extended pilot study were to evaluate further GraphoLearn SI's usability, test the association of progress in GraphoLearn in promoting reading and reading-related skills in first-grade learners of Standard Indonesian, and use the data acquired during this study to improve the game design.

Standard Indonesian Orthography

Standard Indonesian (SI) is a standardized dialect of the Malay language (Sneddon, 2003). For approximately 23 million Indonesians, SI is their primary language, and another 140 million speak SI as a second language (Lewis, Simons, & Fennig, 2013). SI has a highly transparent alphabetic orthography with an almost one-to-one correspondence between phonemes and graphemes in both the reading and spelling direction (i.e., phoneme to grapheme and grapheme to phoneme), including a close correspondence between letter names and letter sounds (Winskel & Widjaja, 2007). The alphabet coincides with the 26 letters of the English alphabet, albeit the letter *x* is only used in loan words. SI has numerous transparent morphemes and affixations (Prentice, 1987). Colloquial SI, however, often features nonaffixed forms. The affixes have at least one semantic function and differ as a function of the word class of the stem. For example, the active verb and stem word *makan* [to eat] becomes the noun *makanan* [food] or the passive verb *termakan* [to be eaten] after adding the suffix *-an* and prefix *ter-*, respectively (Winskel & Widjaja, 2007). The majority of words are multisyllabic; monosyllabic words are rare. The syllable structures are simple and have clear boundaries (Prentice, 1987; Winskel & Lee, 2013). As many textbooks for first-graders already feature words with derivational affixes, Indonesian schoolchildren need to master long words early in their education (Winskel & Widjaja, 2007).

METHODS

Sample

In Indonesia, primary schooling begins at the age of six for most children and is compulsory for all. During reading instruction in the 2nd year of kindergarten (children aged 5 years), students generally start to acquire some letter knowledge. However, the enrollment of children in early childhood programs (e.g., playgroup, kindergarten) is limited in Indonesia, with families living above the poverty line being more likely to enroll their children in such programs than are families living in poverty (World Bank, 2006). Moreover, educational services in Indonesia are biased toward urban areas, where the percentage of children attending preschool programs in 2003 was twice as high as in rural areas (Sardjunani & Suryadi, cited by Sardjunani, Suryadi, & Dunkelberg, 2007).

We recruited 37 first graders from a small private Christian school in one of the suburbs of Medan (Sumatra), where education is provided in SI. The teacher taught all participants using the same teaching method. Reading instruction started with the introduction of the alphabet. Once the students had memorized the letter names, they were taught to combine consonants (C) and vowels (V) to form syllables with a simple CV structure (e.g., *b+u* to produce the syllable *bu*). Subsequently, the students were instructed to combine V and CV syllables patterns to form words (e.g., *i+bu* to create the word *ibu*, meaning mother) before learning syllables with a CVC pattern and more complex CV combinations. All students had a low- to middle-socioeconomic background and were fluent in SI, including one bilingual student who also spoke a regional language (Batak) at home.

Of these 37 candidates, 33 were eligible to participate in the study. Three students were excluded from the data analyses, as their cognitive abilities to play the game were insufficient, whereas the fourth student rarely attended school, missing both pre- and posttest sessions and most of the GraphoLearn sessions.

Table 1 describes the demographics of the 33 participants at the administration of the pretest. Thirty-one students had attended only 1 year of the 2-year kindergarten program, and two students had not attended kindergarten at all.

Measures and Procedure

All students played GraphoLearn SI during various prescheduled supervised group sessions at school in the period between August and November 2015, with the player data recorded onto a server for offline analysis. The students' reading and reading-related skills were assessed during

Table 1. Demographics of the Study Sample at Pretest.

	Grade 1
N	33
Boys; girls	20; 13
Mean age in years for all students [range]	6.5 [5.3–7.3]
SD age	0.65
Kindergarten attendance [boys; girls]	19; 12

three individual test sessions using paper-and-pencil tests completed prior to the start of the GraphoLearn SI training in August (pretest, second or third week of school; *N* = 30), at the end of the training in November (posttest; *N* = 33), and at a follow-up in April 2016 (follow-up; *N* = 31). Moreover, the students participated in a computerized in-game assessment at both pretest and posttest. Two of the 33 students had started school a few weeks late and therefore missed the pretest and, after two attempts, another student proved too shy to take the pretest. In Week 4 of the school year, all students started playing GraphoLearn SI following 3 weeks of formal reading instruction.

The descriptive statistics of the GraphoLearn SI player data are presented in Table 2. Our aim was to have the students play the game five times a week for 13 weeks between August and November, excluding the midterm exam week. We also tracked any lack of play due to school absence or technical issues, which was typical for all children and negatively impacted the goal of five sessions a week. We recorded an average of 2.9 sessions per week with an average playing time of 11.3 minutes per session. These statistics reflect the time during which students were actually exposed to the educational content and had spent completing game levels, excluding the time during which they explored the map between levels. The overall average time spent using the game was 10–15 minutes per session.

The majority of the behavioral measures used were taken from a recently developed assessment battery for beginner readers of SI (Jap, Borleffs, & Maassen, 2017). Additionally, we created and presented an auditory synthesis task (modeled after a Dutch version developed by Verhoeven, 1993, drawing its content from commonly used Indonesian first-grade textbooks), as well as two subtasks from the Snijders-Oomen nonverbal intelligence test (SON-R 6-40; Tellegen & Laros, 2011). When necessary, the instructions were translated into Standard Indonesian, but the original task content was maintained (also see Borleffs et al., 2018).

Table 2. Descriptive Statistics of GraphoLearn Player Data after 13 Weeks (*N* = 33).

	Minimum	Maximum	Mean	Median	*SD*
Total playing time (h)	3.73	9.69	7.13	7.28	1.62
Number of playing sessions	18	50	37.8	39	7.9
Total number of levels played	198	682	457	477	124
Levels played per minute	0.78	1.50	1.07	1.03	0.19
Highest level reached	7	333	193	175	122
Total number of items seen	10,413	35,744	23,930	24,486	7,206
Total number of responses given	2,621	8,813	6,004	6,151	1,658

The following tasks were completed at pretest: SON-R categories and analogies (nonverbal intelligence test), digit span forward and backward, phoneme deletion, auditory synthesis, Rapid Automatized Naming (RAN) objects, colors, and if possible, based on students' sufficient knowledge, digits and letters. The pretest sessions took approximately 35 minutes, on average.

At posttest and follow-up measurements, word reading and pseudoword reading were assessed, in addition to all tests from the pretest, except for the SON-R subtasks. Posttest and follow-up sessions each took approximately 20 minutes, on average. The tests comprised

- WORD READING. We presented the student with a list of 100 lowercase multisyllabic (2–4 syllable) words printed on an A4-size laminated sheet of paper. Reading fluency was defined as the number of words correctly read aloud within 1 minute.
- PSEUDOWORD READING. We presented the student with a list of 100 lowercase multisyllabic pseudowords (2–4 syllable) printed on an A4-size laminated sheet of paper. Decoding fluency was defined as the number of pseudowords correctly read aloud within 2 minutes.
- PHONEME DELETION. The researcher instructed the student to verbally repeat a pseudoword articulated, after which (s)he was asked to leave out a particular phoneme from the presented pseudoword. The phoneme-deletion score was calculated as the number of correct answers.
- AUDITORY SYNTHESIS. The researcher presented 20 words (2–5 phonemes per word) by articulating the individual phonemes one by one, after which the student was asked to blend these sounds into a spoken word. The auditory-synthesis score was calculated as the number of correct answers.
- RAPID AUTOMATIZED NAMING (RAN). We showed the student five columns of 10 objects, colors, digits, or letters printed on A4-size laminated sheets of paper and asked him/her to name these from top to bottom as fast and as accurately as possible. Each RAN subtest score was calculated as the number of items per second correctly named by the student.
- DIGIT SPAN FORWARD AND BACKWARD. The researcher asked the student to repeat spans of digits of increasing lengths, in forward fashion during the first task and in backward fashion during the second. Both digit-span scores were based on the number of correctly reproduced trials.
- CATEGORIES AND ANALOGIES (SON-R 6-40; Tellegen & Laros, 2011). Both SON-R subtasks measured abstract reasoning and consisted of three groups of 12 test items. In the categories task, the student had to find the common characteristic in three pictures and subsequently point at two other pictures (of five new pictures) that also possessed this feature. In the analogies task, the student had to discover the principle of change of an example analogy where one geometrical figure changed into another geometrical figure and apply this principle to another comparable figure. Both SON-R scores were based on the total number of correct answers.

The in-game assessments completed during the pre- and posttest sessions were part of a larger test battery. Below, we describe the assessments analyzed in our present trial:

- LETTER–SOUND KNOWLEDGE-PART I. The researcher asked the student to match a target speech sound to the corresponding grapheme presented on the screen together with seven or eight distractors (e.g., target /d/ with distractors ⟨d | e r i n k a ai⟩).

The score for this test was calculated as the number of correct answers in the 25 presented phonemes.

- LETTER–SOUND KNOWLEDGE-PART II. We asked the student to match a target speech sound to the corresponding grapheme. Each target grapheme was presented on the screen together with five more confusable distractors than in Part I (e.g., target /ŋ/ with distractors ⟨ng | n m g ny y⟩). This second letter–sound knowledge score was calculated as the number of correct answers for the 10 presented phonemes.
- NUMBER KNOWLEDGE. We asked the student to match a spoken digit, ranging from 0 to 20, with the corresponding written representation. Each target was presented on the screen together with 9 or 10 distractors (e.g., target digit 19 with distractors ⟨19 | 1 2 9 17 11 4 15 14 5⟩). The number-knowledge score was calculated as the number of correct answers in the 21 presented digits.
- LEXICAL DECISION (only at posttest). The researcher showed the student 16 words (e.g., *kue, sampai, di*) and 16 pseudowords (*tue, simpau, ki*), one at a time, and asked to decide whether or not the presented word was a real word by selecting a button with a red cross (is not) or a green check mark (is real). The score was calculated as the number of correct answers.

RESULTS

Students' Performance Across Three Test Points

Table 3 lists the performance scores for the pre-, post-, and follow-up tests (16 in total) in mean values and standard deviations and the results from the paired samples *t* test or Wilcoxon signed-rank test. Several variables were not normally distributed, in which case we used the nonparametric alternative for the paired samples *t* test.

As a result of insufficient letter and/or number knowledge, respectively eight and six students were not able to take the RAN letters and/or RAN digits subtest at pretest. If, prior to the RAN subtest (i.e., during the practice activity), a student was not able to correctly name any of the digits or letters in the last column of the pretest (while the rest of the columns were covered), we excused the student from taking the specific subtest. Following the same protocol, missing posttest data were reported for three students on the RAN letters task and for two students on RAN digits. With regard to the SON-R scores, we unfortunately were able to collect scores for only two thirds of the students (22 of 33). We therefore decided to exclude the SON-R scores from further analyses for this paper. Moreover, correlations between SON-R scores and reading fluency were close to zero, showing that the SON-R scores did not relate to reading levels in our sample.

As shown in Table 3, the paired pre–post differences were significant for auditory synthesis, all four RAN tasks, the in-game number-knowledge assessment task, and both letter–sound knowledge tasks. The paired posttest–follow-up differences yielded significant results for reading and decoding fluency, phoneme deletion, and RAN colors, digits, and letters.

Table 3. Descriptive Statistics of the Pre-, Post-, and Follow-up Tests Results and the Paired Posttest–Pretest and Follow-up–Posttest Differences.

	Pretest			**Posttest**			**Follow-up Test**			**Paired Differences Posttest–Pretest**		**Paired Differences Follow-up–Posttest**	
	N	Mean	*SD*	*N*	Mean	*SD*	*N*	Mean	*SD*	*t* / *Z**	Sign.	*t* / *Z**	Sign.
Reading fluency	-	-	-	33	14.7*	16.0	31	28.2*	25.1	-	-	4.23*	<.001**
Decoding fluency	-	-	-	33	17.6*	19.0	31	27.3*	24.8	-	-	3.95*	<.001**
Auditory synthesis	30	1.90*	2.14	33	4.85*	4.24	31	6.77*	5.37	2.99*	.003**	1.76*	.079
Phoneme deletion	30	0.47*	1.01	33	0.45*	1.30	31	2.26*	4.57	-0.30*	.764	2.70*	.007**
Digit span forward	28	4.29	1.80	33	4.76*	1.52	31	4.55*	1.73	1.39*	.164	0.20*	.839
Digit span backward	30	0.80*	1.03	33	1.33*	1.29	31	1.48*	1.15	1.91*	.057	1.19	.232
RAN colors	28	0.43	0.25	31	0.56	0.26	31	0.58	0.27	4.28	<.001**	2.10	.045**
RAN objects	30	0.56	0.18	33	0.68	0.14	31	0.71	0.21	4.55	<.001**	1.45	.159
RAN digits	27	0.61*	0.30	31	0.95*	0.34	31	1.00	0.41	4.54*	<.001**	3.58*	<.001**
RAN letters	25	0.56	0.29	30	0.97	0.42	31	1.10*	0.55	8.13	<.001**	3.44*	.001**
SON analogies	22	5.36*	3.58	-	-	-		-	-	-	-	-	-
SON categories	22	4.68*	4.09	-	-	-		-	-	-	-	-	-
Number knowledge	28	15.9*	6.43	29	18.2*	5.44		-	-	3.06	.002**	-	-
LS knowledge I	28	11.3	5.90	29	15.8	4.88		-	-	2.94	.007**	-	-
LS knowledge II	27	4.78	2.21	27	6.15	1.99		-	-	3.14	.005**	-	-
Lexical decision	-	-	-	29	15.9*	5.09		-	-	-	-	-	-

Note. LS knowledge = letter–sound knowledge. RAN = rapid automatized naming score in items correctly named per second. SON-R = Snijders-Oomen nonverbal intelligence test

* One or both variables are not normally distributed. Nonparametric Wilcoxon signed-rank test is used instead of paired samples *t* test.

** Mean difference is significant at the .05 level

Correlations

Interrelationships among 14 tests (excluding SON-R categories and analogies) and the GraphoLearn (GL) variables mentioned in Tables 2 and 3 were examined using a correlation matrix (Spearman's rho) and are listed in Table 4. Notable are the significant posttest correlations between the GL variables highest level achieved and levels completed per minute and the phonological awareness tasks (a) phoneme deletion and (b) auditory synthesis, both of which were lacking significance at the pretest. By contrast, looking at both the letter–sound knowledge and number knowledge tasks in relation to the GL variables, we generally found higher correlations for the pretest than for the posttest scores. As for the RAN tasks, we found significant correlations with several GL variables at all three test sessions, with the correlations generally being most apparent at posttest.

As shown, both posttest and follow-up reading and decoding fluency scores correlate significantly with the highest GL level reached and the number of levels played per minute. At follow-up, reading and decoding fluency additionally correlate significantly with the total number of levels played. The correlation data hence show that game progress is related to reading and decoding skills. No significant correlations were found between post- or follow-up reading and decoding fluency and (a) total playing time, (b) the number of sessions played, (c) the number of items seen, or (d) the number of responses given. The latter four GL variables all relate to the duration and the number of learning opportunities that were provided to the student. They do not provide information, however, about the extent to which the student is able to profit from these learning opportunities, his/her reading and decoding level, or his/her ability to translate GL learning into improved real-life reading and decoding skills.

In Table 5a, the intercorrelations between pretest (lightly shaded part) and posttest performance (unshaded part) are provided; correlations at follow-up are listed in Table 5b. In the darkly shaded part of Table 5a, a number of pretest–posttest correlations are presented to investigate relations between pretest reading-related skills and posttest reading and decoding abilities.

Reading and decoding fluency correlate significantly with all tasks at posttest and follow-up, with the exceptions of the posttest lexical decision task, the posttest and follow-up digit span backward, and the follow-up digit span forward. Due to the data not being normally distributed, no factor analyses could be conducted. However, the correlations do show a factor structure, with reading and decoding fluency correlating strongly to each other at posttest and follow-up, being about equally high at both test points. Moreover, all four RAN tasks correlate significantly with each other at all three test sessions. Auditory synthesis correlates with phoneme deletion at pretest and follow-up, but not at posttest. Pretest auditory synthesis and phoneme deletion in general show relatively low correlations with other reading-related skills at pretest, in line with the nonsignificant correlations with GL variables presented at the start of this paragraph.

No significant correlation was observed between digit span forward or backward at any of the three test sessions. This is due possibly to the digit span backward seeming to be relatively difficult for all students regardless of their performance on digit span forward, with mean scores of 0.80 on pretest, 1.33 on posttest, and 1.48 on follow-up for digit span backward, compared to 4.29 on pretest, 4.76 on posttest, and 4.55 on follow-up for digit span forward. Digit span backward only correlates significantly with pretest auditory synthesis and posttest phoneme deletion. We found no significant correlations at follow-up for digit span backward.

Table 4. Spearman Correlations for the GraphoLearn Variables and Reading and Reading-Related Skills at the Pre-, Post-, and Follow-up Tests.

	GraphoLearn						
	Highest level	Playing time	Levels total	Levels per min	Sessions total	Items seen	No. of responses
Pretest							
Auditory synthesis	.360	.107	.136	.153	-.052	.168	.147
Phoneme deletion	.258	.083	.183	.246	.016	.169	.174
Digit span forward	.432*	-.137	.174	.431*	-.181	.015	-.021
Digit span backward	.356	.084	.126	.167	.051	.171	.153
RAN colors	.553**	-.377*	.221	.667**	-.397*	-.033	-.042
RAN objects	.332	.003	.260	.458*	-.090	.129	.132
RAN digits	.362	-.052	.123	.302	-.063	.024	.030
RAN letters	.693**	-.316	.179	.618**	-.415*	-.156	-.181
Number knowledge	.896**	.256	.542**	.574**	.091	.376*	.339
LS knowledge I	.738**	.101	.340	.382*	-.109	.228	.219
LS knowledge II	.658**	.095	.361	.570**	-.038	.178	.179
Posttest							
Reading fluency	.811**	-.155	.321	.670**	-.315	.078	.041
Decoding fluency	.801**	-.193	.321	.679**	-.313	.092	.049
Auditory synthesis	.564**	.126	.468**	.473**	-.002	.314	.287
Phoneme deletion	.406*	-.259	-.076	.392*	-.336	-.091	-.126
Digit span forward	.527**	.026	.266	.399*	.046	.139	.091
Digit span backward	.474**	.122	.153	.190	.014	.134	.104
RAN colors	.590**	-.146	.319	.540**	-.203	.023	.015
RAN objects	.351*	-.050	.313	.474**	-.074	.176	.157
RAN digits	.664**	.105	.495**	.525**	.006	.335	.321
RAN letters	.798**	-.110	.434*	.673**	-.122	.136	.110
Number knowledge	.718**	.181	.342	.487**	.145	.149	.118
LS knowledge I	.489**	.049	.243	.399*	.015	.083	.061
LS knowledge II	.576**	-.196	.139	.486*	-.243	-.029	-.056
Lexical decision	.255	-.277	-.026	.167	-.288	-.094	-.109
Follow-up							
Reading fluency	.798**	.033	.480**	.660**	-.107	.262	.242
Decoding fluency	.848**	.025	.555**	.722**	-.100	.303	.279
Auditory synthesis	.662**	-.114	.344	.543**	-.187	.169	.156
Phoneme deletion	.262	-.338	-.136	.223	-.408*	-.181	-.207
Digit span forward	-.005	-.236	.025	.156	-.149	-.044	-.066
Digit span backward	.387*	.044	.205	.230	-.049	.289	.286
RAN colors	.573**	.090	.515**	.592**	.004	.332	.340
RAN objects	.272	-.100	.217	.264	-.162	.072	.069
RAN digits	.606**	.294	.600**	.531**	.202	.525**	.521**
RAN letters	.689**	.252	.614**	.612**	.162	.426*	.411*

Note. LS knowledge = letter–sound knowledge. RAN = Rapid Automatized Naming.
* Correlation is significant at the 0.05 level (2-tailed) ** Correlation is significant at the 0.01 level (2-tailed)

Table 5a. Spearman Correlations for Reading and Reading-Related Skills at Pretest (light shaded), Posttest (unshaded), Pretest with Posttest (diagonal boxes), and for Posttest (Reading, Decoding) with Pretest (dark shaded).

	Auditory synthesis	Phoneme deletion	Digit span-forward	Digit span-backward	RAN colors	RAN objects	RAN digits	RAN letters	Number knowledge	LS knowledge I	LS knowledge II	Reading fluency	Decoding fluency
Auditory synthesis	.207	.450*	.240	.537**	.287	.191	.273	.214	.625**	.477*	.318	.290	.328
Phoneme deletion	.187	.324	.095	.065	.401*	.456*	.314	.196	.207	.269	.186	.269	.258
Digit span-forward	.532**	.158	.557**	.270	.596**	.320	.176	.351	.403*	.237	.148	.276	.257
Digit span-backward	.084	.375*	.230	.465**	.197	-.067	.406*	.133	.599**	.349	.232	.239	.284
RAN colors	.414*	.347	.460**	.214	.773**	.574**	.421*	.688**	.405*	.241	.156	.542**	.553**
RAN objects	.456**	.310	.312	.019	.608**	.617**	.515**	.457*	.220	.149	.040	.313	.306
RAN digits	.551**	.163	.625**	.137	.590**	.573**	.566**	.435*	.479*	.183	.048	.452*	.465*
RAN letters	.580**	.348	.514**	.197	.603**	.471**	.745**	.670**	.625**	.457*	.243	.761**	.761**
Number knowledge	.538**	.461*	.593**	.517**	.357	.364	.513**	.551**	.800**	.722**	.555**	.695**	.718**
LS knowledge I	.447*	.007	.248	.106	.018	.038	.152	.379	.503**	.215	.605**	.617**	.634**
LS knowledge II	.458*	.378	.393*	.270	.247	.259	.289	.503*	.650**	.622**	.613**	.612**	.578**
Reading fluency	.490**	.453**	.481**	.300	.564**	.428*	.608**	.731**	.601**	.440*	.735**	-	-
Decoding fluency	.506**	.463**	.475**	.256	.555**	.519**	.631**	.792**	.600**	.449*	.707**	.969**	-
Lexical decision	-.034	.086	.257	.117	.057	-.063	.257	.032	.285	.055	.219	.277	.289

Note. LS knowledge = letter–sound knowledge. RAN = Rapid Automatized Naming.
* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

Table 5b. Spearman Correlations between Reading and Reading-Related Skills at Follow-up.

	Auditory synthesis	Phoneme deletion	Digit span-forward	Digit span-backward	RAN colors	RAN object	RAN digits	RAN letters	Reading fluency	Decoding fluency
Auditory synthesis	1.000	.364*	.361*	.326	.574**	.370*	.537**	.674**	.710**	.723**
Phoneme deletion		1.000	.263	.156	.230	.168	.067	.304	.512**	.436*
Digit span forward			1.000	.092	.179	.049	-.018	.150	.143	.142
Digit span backward				1.000	.438*	.133	.216	.174	.277	.280
RAN colors					1.000	.505**	.565**	.528**	.485**	.539**
RAN objects						1.000	.633**	.525**	.358*	.434*
RAN digits							1.000	.792**	.676**	.692**
RAN letters								1.000	.835**	.829**
Reading fluency									1.000	.931**
Decoding fluency										1.000

Note. * Correlation is significant at the 0.05 level (2-tailed) ** Correlation is significant at the 0.01 level (2 tailed).

The results in the dark shaded part of Table 5a show a consistent pattern of strong correlations for both posttest reading and posttest decoding fluency with pretest RAN colors and letters, pretest number knowledge, and both pretest letter–sound knowledge tasks. At the $\alpha = .05$ level, both posttest variables additionally correlate with pretest RAN digits.

Regression

We conducted a linear regression analysis to determine whether posttest and follow-up reading and decoding fluency was predicted by progress in the game. Considering the high correlations between reading and decoding fluency at posttest and follow-up (.969 and .931, respectively), the composite scores posttest fluency (combining posttest reading and decoding fluency) and follow-up fluency (combining follow-up reading and decoding fluency) were created by averaging *z* scores and were used as dependent variables in the linear regression models. A similar calculation was performed to create pretest letter-sound (LS) knowledge, combining pretest letter–sound knowledge Parts I and II. Letter knowledge has been shown to be an important predictor of initial reading skills, especially in transparent orthographies (Caravolas, Lervåg, Defior, Seidlová-Málková, & Hulme, 2013; Lyytinen et al., 2008; Winskel & Widjaja, 2007). By adding pretest LS knowledge first to the hierarchical linear regression model, we were able to control for previous letter–sound knowledge. Subsequently, all GL variables (i.e., total playing time, number of playing sessions, total number of levels played, levels played per minute, highest level reached, total number of items seen, and total number of responses given) were added stepwise, in addition to the interaction variables that were created for each GL parameter with the composite score pretest LS knowledge. The strongest predictors (i.e., largest R^2, highest β) were included in the final model, as shown in Table 6. Prior to each regression analysis, we checked whether the standardized residuals of the variables included were normally distributed, which they were.

We found a significant main effect for pretest LS knowledge on posttest fluency in the first step of the hierarchical regression analysis (*ß* = 0.68, $t = 4.64$, $p < .001$), but pretest LS knowledge was no longer significant after including the individual variables and their interactions with pretest LS knowledge (see Table 6). In the final model, highest GL level reached and GL sessions total were shown to be significant predictors of posttest fluency, the latter variable having a negative standardized beta. Adding the GL sessions total first, before including highest GL level reached in the final model, resulted in a smaller R^2 change (.114) than the R^2 change for highest GL level reached (.144), and hence did not improve the final model's fit. After controlling for baseline LS knowledge and the highest GL level reached, the total number of sessions played hence became a negative predictor of posttest fluency. Worth noting is that 10 of the 33 students (30%) had completed all 333 levels prior to or by the end of the last (i.e., 50th) GL session, with an average of 37 sessions (range: 27–50) and 7.19 playing hours (range: 5.69–9.49; *SD*: 1.29). Six students (18%), on the other hand, were still struggling with the first 20% of the levels (i.e., Level 66 and below) after a mean of 35 sessions (range: 24–46) and 5.97 hours (range: 4.03–9.11; *SD*: 1.70) of gameplay. Eighteen percent of our sample hence played for several hours over a large number of sessions but still were not able to make substantial progress in the game and reach high posttest fluency levels. As mentioned previously in the correlations section of this paper, the highest GL

Table 6. Linear Regression Equations with Posttest/Follow-up Fluency as the Dependent Variable.

		ß	*t*	*p*-value	R^2	*F*	*df*	*p*-value
Dependent variable	**Independent variables**				**Full model**			
Posttest fluency	Pretest LS knowledge	.68	4.64	<.001*	**.46**	**21.51**	**1,26**	**<.001***
(Model 1)	Pretest LS knowledge	.22	1.52	.141				
	Highest GL level	.63	4.45	<.001*				
	GG Sessions total	-.41	-4.09	<.001*	**.77**	**26.02**	**3,26**	**<.001***
Posttest fluency	Pretest LS knowledge	-.132	-.51	.614				
(Model 2)	Highest GL level	.486	2.88	.008*				
	Highest GL level x Pretest LS	.540	2.22	.036*	**.68**	**16.00**	**3,26**	**<.001***
Follow-up fluency	Pretest LS knowledge	.67	4.44	<.001*	**.45**	**19.67**	**1,25**	**<.001***
	Pretest LS knowledge	.18	1.11	.278				
	Highest GL level	.70	4.34	<.001*	**.70**	**26.57**	**2,25**	**<.001***

Note. Posttest-fluency = composite variable for posttest reading fluency and posttest decoding fluency. Pretest LS knowledge = composite variable for pretest letter–sound knowledge parts I and II. GL = GraphoLearn. Highest level x Pretest LS = interaction variable Highest GL level x Pretest LS knowledge.

* Significant at the 0.05 level. Pretest letter–sound knowledge was added first to the models presented; all GL parameters were added simultaneously after.

level reached relates to game progress. The sessions total, however, relates to the number and duration of learning opportunities provided to the student, but it does not provide information about the extent to which the student is able to profit from these learning opportunities, the attained reading and decoding level, or the ability to translate GL learning into improved real-life reading and decoding skills. When excluding the duration parameter GL sessions total from the model, a significant pretest LS Knowledge × Highest GL Level reached interaction effect was observed, aside from the significant main effect for the highest GL level reached on posttest fluency (see lower part of Table 6).

At follow-up, a similar pattern of prediction was found for pretest LS knowledge. The pretest LS knowledge variable contributed significantly to the prediction of follow-up fluency by itself, as is shown by the regression results (*ß* = 0.67, *t* = 4.44, *p* < .001; see Table 6). In the final regression model, however, highest GL level reached became the only significant contributor to the prediction of follow-up fluency (*ß* = 0.70, *t* = 4.34, *p* = < .001). No significant interaction effects were observed for follow-up fluency.

To further investigate the interaction of the highest GL level reached and pretest LS knowledge, we plotted the model predictions in Figure 1 for low (≤ -1) and high (≥ +1) *z* scores on the highest GL level reached and, for continuous standardized data, on pretest LS knowledge. Mean posttest reading and decoding fluency scores (as combined in the composite score posttest fluency) of students with average to above-average pretest LS knowledge (*z* scores > -1) differed significantly between the two GL progress levels. Figure 1 shows that the posttest reading and decoding performance of students with below-average pretest letter–sound knowledge was not moderated by the amount of game progress made. For students with average to above-average letter–sound knowledge, the model described a significant difference in posttest reading and decoding fluency scores between low and high game progress.

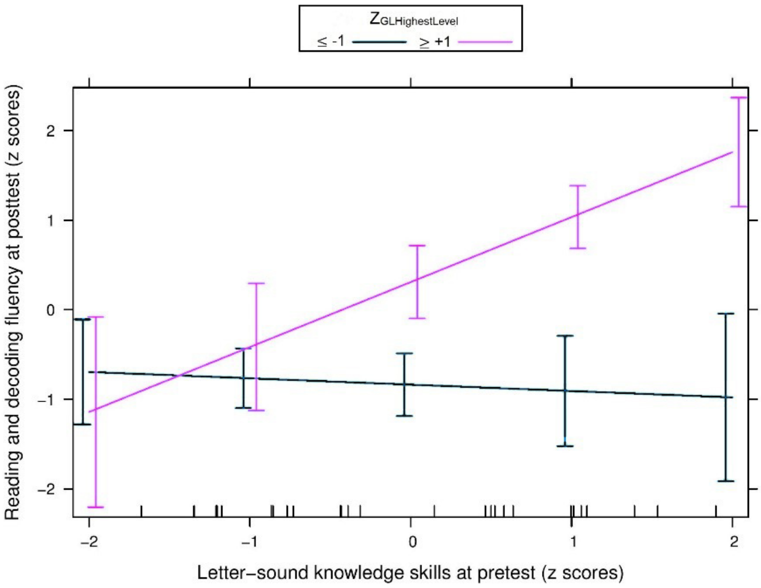

Figure 1. Plot of the pretest LS Knowledge × Highest GL Level interaction effect, with posttest fluency as the dependent variable.

Note. LS knowledge = composite variable for pretest letter–sound knowledge parts I and II. GL = GraphoLearn. $Z_{GLHighestLevel}$ = *z* score GL highest level reached

DISCUSSION

This current pilot study provides a next step in the assessment of GraphoLearn SI as a playful, efficient, and effective intervention promoting reading and reading-related skills in beginning readers. An earlier published study (Borleffs et al., 2018) showed promising results for the compressed version of the game for typical and struggling first-grade readers in a school in the Indonesian city of Medan. In the present study, we tested the main design of GraphoLearn SI with first graders of an elementary school situated on the outskirts of Medan. In our intervention, we aimed at five 10–15 minute playing sessions per week for optimal concentration and automatization of reading-related skills (see also Richardson & Lyytinen, 2014), in line with other GraphoLearn effectiveness studies (e.g., Kyle et al., 2013; Saine et al., 2010).

Although large-scale randomized controlled studies are needed to confirm the effectiveness of GraphoLearn SI, our correlation results show that progress in the game (as measured by the highest game level reached, the total number of levels played, and the average number of levels played per minute) and several of the assessed reading-related skills are significantly related to reading and decoding fluency skills. Our regression analyses point out that, in the present sample, the highest GL level reached was the most important predictor of reading and decoding fluency at posttest, as well as at the 5-month follow-up assessment. We also noted a moderation effect of the highest level reached on the posttest reading and decoding abilities of students with average to above-average pretest letter–sound knowledge: The better the students' knowledge of grapheme–phoneme correspondences at pretest, the larger the effect of game progress was in terms of reading and decoding fluency at posttest. No such significant difference was found between high and low game progress in students with below-average letter–sound knowledge at pretest.

A challenge GraphoLearn SI likely shares with other reading-support methods is that, at the start of first grade, students' initial reading-related skills can vary greatly. The results presented above indicate that students may need a basic level of understanding of grapheme–phoneme correspondences to be able to profit sufficiently from the game. Thirty-one of the 33 first graders we tested in this study come from low- to middle-socioeconomic backgrounds and had attended kindergarten for 1 year only; two students did not attend kindergarten at all. Initial levels of reading-related skills varied greatly on some pretest tasks and may have been, on average, slightly lower in our sample than they might have been among urban first graders from higher socioeconomic families with 2 full years of kindergarten.

As mentioned in the correlation section of this paper, we generally obtained low pretest correlations for both phonological awareness tasks and other reading-related skills. With mean pretest scores of 1.90 and 0.47, respectively, on phoneme deletion and auditory synthesis, these nonsignificant correlations with highest level and levels per minute may have been caused partly by a floor effect. Especially in transparent orthographies in which letters correspond to sounds in a highly predictable way, letter knowledge has been shown to be a powerful predictor of early reading acquisition (Caravolas et al., 2013; Lyytinen et al., 2008; Winskel & Widjaja, 2007). Phonological awareness and reading may be reciprocally rather than causally related (see also Blomert & Willems, 2010; Ziegler et al., 2010), with these skills developing later, contingent upon reading acquisition progress.

Reading acquisition in the SI language has not been studied extensively to date, and some of the tests we used still require further optimization and validation (see also Borleffs et al., 2018; Jap et al., 2017). Other limitations of our pilot study are the relatively small sample size and the fact that all the students stemmed from lower- to middle-socioeconomic families, attended the same elementary school, and all but one spoke SI as their first language. Hence, our results cannot be generalized to the wider Indonesian primary-school population. Large-scale studies gauging beginning readers from various ethnic and socioeconomic backgrounds living in different parts of Indonesia, attending both private and public schools in urban and rural areas, and using active and passive control groups are required to establish the wider effectiveness of GraphoLearn SI in promoting reading and reading-related skills.

Considering that the main design of GraphoLearn SI merely offers players more opportunities to practice the same game content as the compressed version, our research group (see also Borleffs, 2018; Borleffs et al., 2018) questioned the benefit of extended training for students who can attain decoding fluency with regular classroom instruction and the compressed version, that is, playing 1–2 hours spread out over several weeks and sessions. Due to SI's highly transparent orthography (Winskel & Widjaja, 2007), fluency in word decoding is expected to be attained by learning the grapheme–phoneme correspondences and then by putting them together the different sounds of written words (Richardson & Lyytinen, 2014). We researchers (see, e.g., Borleffs et al., 2018) have argued that, for proficient players, the compressed game design may already provide sufficient practice to ensure automatization of decoding skills, whereas struggling players may benefit more from the fuller main design, where the extra practice may help improve their lagging reading and decoding skills.

CONCLUSIONS

The present pilot study evaluating the main GraphoLearn SI design further validates our previous digital reading intervention (see also Borleffs, 2018; Borleffs et al., 2018) by showing once more that a relationship exists between game progress and reading and decoding proficiency, as tested shortly after the last playing session and 5 months later. The present results also revealed that even after an average of thirty-five 10-minute playing sessions, six students from our current sample still showed persistent reading and decoding difficulties.

Various factors may have influenced our results in part. In future research, it may be worthwhile to assess as well other reading-related classroom activities, familiarity with the use of a computer (even though a short training was provided to all students in this study), or familiarity with the type of assessment used (see also Borleffs, 2018). Student motivation also raises an interesting variable to incorporate into future research. During the present pilot study, teachers reported to be pleased with the students' progress and that students generally seemed to enjoy playing the game. Future research also may find that persistently struggling readers require more explicit instructions and feedback than our current game environment provides.

Moreover, such struggling new readers might be at risk of developing serious reading deficits. Future research will need to uncover why some students do and others do not seem to benefit sufficiently from the game and what adjustments are necessary to increase GraphoLearn SI's effectiveness. Potentially, maintaining the same workable playing frequency (i.e., about three 10-min sessions per week) but extending the playing period from 13 weeks to 4 to 6 months may enable the poorer readers to benefit from the game. For those struggling students, 13 weeks of gameplay may have been too short to establish firmly their letter–sound knowledge and to build up their phonological awareness skills (see Glatz et al., 2018, for a similar view).

Furthermore, based on the preliminary but promising results we obtained with GraphoLearn SI so far, another aspect worth investigating is whether this learning tool might have potential as a diagnostic instrument in the early identification of readers at risk of developing serious reading deficits or dyslexia, while simultaneously offering additional learning opportunities (see Borleffs, 2018). Future studies are needed to investigate whether such a digital tool could be integrated into teaching practices and be used effectively to diagnose and support struggling readers. This will depend also on access to suitable equipment and Internet connections at schools, as well as the teachers' attitude toward classroom technology, where cultural and age-related factors may play a role.

The advantages of an online digital game environment are enormous in that, for instance, playing time and progress can be monitored easily, student exposure to a large number of high-quality stimuli is extensive, the player's progress is synchronized across all connected devices, and the game is updated automatically. Still, the lack of availability of sufficient digital devices at school and/or at home may present the most fundamental obstacle in how students gain access to the game (Ojanen et al., 2015; Richardson & Lyytinen, 2014). However, with Internet subscriptions and technological devices becoming more affordable and with the number and spread of digital devices increasing rapidly around the world, this will hopefully become increasingly less consequential in the near future for students in developing countries such as Indonesia.

IMPLICATIONS FOR RESEARCH, APPLICATION AND POLICY

The findings in this study mirror many other investigations of the benefits of early intervention in reading skills development, particularly those employing the GraphoLearn environment. However, our new knowledge about the length of the training period and playing frequency can benefit new readers now and open lines of further research for the future. Specifically, our findings support suggestions for future research to enable struggling readers to similarly benefit from the game. This is bolstered by our statistical evidence regarding specific game variables that contribute to successfully mastering early reading skills, as well as the impact of orthographic transparency on reading acquisition in general. The findings of this paper can assist future researchers in identifying further challenges to young students mastering reading skills in transparent orthographies and can be a stepping stone for the development of additional language versions of GraphoLearn or similar digital-based reading environments.

Moreover, our results support the application of digital game environments for reading skills development within the classroom, in conjunction with teachers' pedagogical plans. Game environments such as GraphoLearn can support teachers in identifying struggling early readers and offer one option for providing the students with evidence-based learning opportunities to practice fundamental reading skills in their respective language. The application of intervention programs such as GraphoLearn can play an important role in preventing illiteracy or alleviating difficulties resulting from dyslexia.

Finally, given the promising results in this study (and others) that early readers benefit from interventions such as GraphoLearn, government-level educators in Indonesia can make a case for investing in these types of programs to boost reading skill before the struggling students fall too far behind their more reading-capable peers.

ENDNOTES

1. GraphoLearn is the registered trademark of the University of Jyväskylä and the Niilo Mäki Foundation for the noncommercial computerized game aimed at learning to read. The game used in this study was programed and owned by the University and employed for research purposes only. GraphoGame, the commercial version of the learning program, is now owned by Grapho Group Ltd. At the time of our study, there was no distinction between the research version and the commercial version, with both available as GraphoGame. However, in this paper, we refer to the learning environment employed in our research as GraphoLearn (no matter what the research version was called in the past) to be consistent with the current research version.
2. This pilot study was conducted in collaboration with the University of North Sumatra (Indonesia) and the University of Jyväskylä (Finland). The general aims of this study, resulting in a doctoral dissertation (Borleffs, 2018), were (a) to gain more insight into orthographic differences between alphabetic languages and their impact on reading and dyslexia, (b) to create a battery of tests to facilitate assessing reading difficulties in young readers of the SI language, and (c) to develop an SI version of GraphoLearn, a computer-based reading intervention, and test its effectiveness among first-grade students.

REFERENCES

Beddington, J., Cooper, C. L., Field, J., Goswami, U., Huppert, F. A., Jenkins, R., Jones, H. S., Kirkwood, T. B. L., Sahikian, B. J., & Thomas, S. M. (2008). The mental wealth of nations. *Nature, 455*, 1057–1060.

Blomert, L., & Willems, G. (2010). Is there a causal link from a phonological awareness deficit to reading failure in children with familiar risk for dyslexia? *Dyslexia, 16*, 300–317. https://doi.org/10.1002/dys.405

Borleffs, L. E. (2018). *Cracking the code: Towards understanding, diagnosing and remediating dyslexia in Standard Indonesian* (doctoral dissertation). Groningen, the Netherlands: Rijksuniversiteit Groningen.

Borleffs, E., Glatz, T. K., Daulay, D. A., Richardson, U., Zwarts, F., & Maassen, B. A. M. (2018). GraphoGame SI: The development of a technology-enhanced literacy learning tool for Standard Indonesian. *European Journal of Psychology of Education, 33,* 595–613. https://doi.org/10.1007/s10212-017-0354-9

Brem, S., Bach, S., Kucian, K., Guttorm, T. K., Martin, E., Lyytinen, H., Brandeis, D., & Richardson, U. (2010). Brain sensitivity to print emerges when children learn letter–speech sound correspondences. *Proceedings of the National Academy of Sciences, 107,* 7939–7944. https://doi.org/10.1073/pnas.0904402107

Caravolas, M., Lervåg, A., Defior, S., Seidlová-Málková, G., & Hulme, C. (2013). Different patterns, but equivalent predictors, of growth in reading in consistent and inconsistent orthographies. *Psychological Science, 24,* 1398–1407. https://doi.org/10.1177/0956797612473122

Cortiella, C., & Horowitz, S. H. (2014). *The state of learning disabilities: Facts, trends and emerging issues.* New York, NY, USA: National Center for Learning Disabilities.

Glatz, T., Tops, W., Borleffs, E., Richardson, U., Maurits, N., Desoete, A., & Maassen, B. (2018). Dynamic assessment of the effectiveness of digital game-based literacy training in beginning readers. Manuscript submitted for publication.

Holopainen, L., Ahonen, T., & Lyytinen, H. (2002). The role of reading by analogy in first grade Finnish readers. *Scandinavian Journal of Educational Research, 46,* 83–98. https://doi.org/10.1080/00313830120115624

Jap, B. A. J., Borleffs, E., & Maassen, B. A. M. (2017). Towards identifying dyslexia in Standard Indonesian: The development of a reading assessment battery. *Reading and Writing, 30,* 1729–1751. https://doi.org/10.1007/s11145-017-9748-y

Kyle, F., Kujala, J., Richardson, U., Lyytinen, H., & Goswami, U. (2013). Assessing the effectiveness of two theoretical motivated computer-assisted reading interventions in the United Kingdom: GG Rime and GG Phoneme. *Reading Research Quarterly, 48,* 61–76. https://doi.org/10.1002/rrq.038

Landerl, K. (2000). Influences of orthographic consistency and reading instruction on the development of nonword reading skills. *European Journal of Psychology of Education, 15,* 239–257. https://doi.org/10.1007/BF03173177

Lewis, M. P., Simons, G. F., & Fennig, C. D. (Eds.). (2013). *Ethnologue: Languages of the World* (17th ed.). Dallas, TX, USA: SIL International.

Lovio, R., Halttunen, A., Lyytinen, H., Näätänen, R., & Kujala, T. (2012). Reading skill and neural processing accuracy improvement after a 3-hour intervention in preschoolers with difficulties in reading-related skills. *Brain Research, 1448,* 42–55. https://doi.org/10.1016/j.brainres.2012.01.071

Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). A definition of dyslexia. *Annals of Dyslexia, 53,* 1–14. https://doi.org/10.1007/s11881-003-0001-9

Lyytinen, H., Erskine, J., Ahonen, T., Aro, M., Eklund, K., Guttorm, T., Hintikka, S., Hamalainen, J., Ketonen, R., Laakso, M.-L., Leppanen, P. H. T., Lyytinen, P., Poikkeus, A.-M., Puolakanaho, A., Richardson, U., Salmi, P., Tolvanen, A., Torppa, M., & Viholainen, H. (2008). Early identification and prevention of dyslexia: Results from a prospective follow-up study of children at familial risk for dyslexia. In G. Reid, A. Fawcett, F. Manis, & L. Siegel (Eds.), *The SAGE handbook of dyslexia* (pp. 121–146). London, UK: Sage Publishers.

Ojanen, E., Ronimus, M., Ahonen, T., Chansa-Kabali, T., February, P., Jere-Folotiya, J., Kauppinen, K.-P., Ketonen, R., Ngorosho, D., Pitkänen, M., Puhakka, S., Sampa, F., Walubita, G., Yalukanda, C., Pugh, K., Richardson, U., Serpell, R., & Lyytinen, H. (2015). GraphoGame: A catalyst for multi-level promotion of literacy in diverse contexts. *Frontiers in Psychology, 6,* 1–30. https://doi.org/10.3389/fpsyg.2015.00671

Peterson, R. L., & Pennington, B. F. (2015). Developmental dyslexia. *Annual Review of Clinical Psychology, 11,* 283–307. https://doi.org/10.1146/annurev-clinpsy-032814-112842

Prentice, D. J. (1987). Malay (Indonesian and Malaysian). In B. Comrie (Ed.), *The world's major languages* (pp. 913–935). London, UK: Croom Helm.

Richardson, U., & Lyytinen, H. (2014). The GraphoGame method: The theoretical and methodological background of the technology-enhanced environment for learning to read. *Human Technology, 10,* 39–60. https://doi.org/10.17011/ht/urn.201405281859

Saine, N. L., Lerkkanen, M.-K., Ahonen, T., Tolvanen, A., & Lyytinen, H. (2010). Predicting word-level reading fluency outcomes in three contrastive groups: Remedial and computer-assisted remedial reading intervention, and mainstream instruction. *Learning and Individual Differences, 20,* 402–414. https://doi.org/10.1016/j.lindif.2010.06.004

Saine, N. L., Lerkkanen, M.-K., Ahonen, T., Tolvanen, A., & Lyytinen, H. (2011). Computer-assisted remedial reading intervention for school beginners at risk for reading disability. *Child Development, 82,* 1013–1028. https://doi.org/10.1111/j.1467-8624.2011.01580.x

Sardjunani, N., Suryadi, A., & Dunkelberg, E. (2007). Indonesia: Public financing of block grants for privately delivered services. In M. E. Young & L. M. Richardson (Eds.), *Early child development, from measurement to action: A priority for growth and equity* (pp. 233–252). Washington, DC, USA: World Bank.

Sneddon, J. (2003). *The Indonesian language: Its history and role in modern society.* Sydney, Australia: University of New South Wales.

Tellegen, P. J., & Laros, J. A. (2011). *SON-R 6-40. Snijders-Oomen niet-verbale intelligentietest. I. Verantwoording* [The Snijders-Oomen nonverbal intelligence test. I. Justification]. Amsterdam, the Netherlands: Hogrefe uitgevers.

Verhoeven, L. (1993). *Grafementoets. Toets voor Auditieve Synthese. Handleiding* [Grapheme test. Measure for auditory synthesis. Manual]. Arnhem, the Netherlands: Cito.

Winskel H., & Lee, L. W. (2013). Learning to read and write in Malaysian/Indonesian: A transparent alphabetic orthography. In H. Winskel & P. Padakannaya (Eds.), *South and Southeast Asian psycholinguistics* (pp. 179–183). Cambridge, UK: Cambridge University Press.

Winskel, H., & Widjaja, V. (2007). Phonological awareness, letter knowledge, and literacy development in Indonesian beginner readers and spellers. *Applied Psycholinguistics, 28,* 23–43. https://doi.org/10.1017/S0142716407070026

World Bank. (2006). *Indonesia: Early childhood education and development project.* Washington, DC, USA: World Bank. Available at http://documents.worldbank.org/curated/en/128861468283753678/Indonesia-Early-Childhood-Education-and-Development-Project

Ziegler, J. C., Bertrand, D., Tóth, D., Csépe, V., Reis, A., Faísca, L., Saine, N., Lyytinen, H., Vaessen, A., & Blomert, L. (2010). Orthographic depth and its impact on universal predictors of reading: A cross-language investigation. *Psychological Science, 21,* 551–559. https://doi.org/10.1177/0956797610363406

Authors' Note

The authors thank the students, their parents, and the participating school for their cooperation. Additionally, the authors thank Debby A. Daulay and Indri K. Nasution (University of Sumatera Utara, Medan, Indonesia) for facilitating access to the schools and assisting during data collection.

All correspondence should be addressed to
Elisabeth Borleffs c/o B. A. M. Maassen
Center for Language and Cognition Groningen (CLCG)
University of Groningen
P.O. Box 716
9700 AS Groningen, the Netherlands
b.a.m.maassen@rug.nl

Human Technology
ISSN 1795-6889
www.humantechnology.jyu.fi