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First- and Second-Language Learnability Explained by Orthographic Depth and Orthographic Learning: A “Natural” Scandinavian Experiment

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ABSTRACT

Effects of orthographic depth on orthographic learning ability were examined in 10- to 13-year-old children who learnt to read in similar orthographies differing in orthographic depth, defined as consistency of grapheme-to-phoneme correspondences. Danish children who learnt to read a deep orthography underperformed their Swedish counterparts who acquired a shallow orthography on vocabulary, phonological working memory, orthographic learning ability, and a range of first-language (L1: Danish/Swedish) and second-language (L2: English as a foreign language) measures. Orthographic learning ability explained over and above vocabulary and phonological working memory the better performance of Swedish children in comparison with Danish children on L1 reading accuracy and fluency, spelling, and visual word familiarity. With respect to L2 learning, orthographic learning ability determined spelling and visual word familiarity over and above L2 vocabulary and phonological working memory. It is concluded that shallow orthographies promote orthographic learning ability more efficiently than deep orthographies.

The best illustration of a deep orthography was undoubtedly presented in a Monty Python sketch, in which Graham Chapman insists that his name *Raymond Luxury Yacht* should be pronounced *Throat Wobbler Mangrove*. The pronunciation of nearly all print is initially unfamiliar to beginning readers. At school, children first learn how letters are pronounced and then learn to read words by consecutively translating each letter (grapheme) into a sound (phoneme) and blending the sounds into a whole-word sound, a process called phonological recoding. Alternatively, look-and-say methods or a mix of decoding and whole word strategies are used for words such as *yacht*, the 16th-century Dutch spelling for “jot” introduced by printers from Holland, which cannot be deciphered by applying grapheme–phoneme conversion rules. The pronunciation must be looked up in the lexicon. Thus, two processes are involved in word recognition: (a) phonological recoding, and (b) visual-orthographic look-up, coined by Coltheart (1984) as the dual route model of reading.

Orthographic depth

The relative degree to which phonological recoding and visual-orthographic look-up are used depends upon the transparency of the grapheme–phoneme correspondences languages display. Katz and Frost (1992) called this “orthographic depth” and postulated that learning to read and spell should be easier in shallow orthographies, in which letter-sound relations are more consistent than in deep orthographies, in which the relations between graphemes and phonemes are opaque.

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According to Schmalz, Marinus, Coltheart, and Castles (2015), orthographic depth has two broad dimensions: morphological transparency and phonological transparency. Some orthographies sacrifice phonological transparency for morphological transparency (English *sign* and *signal* are semantically related and therefore have identical spelling patterns but different pronunciations, whereas *bee* and *be* are not related and have similar pronunciations but different spelling patterns). Other orthographies sacrifice morphological transparency for phonological transparency such as in Dutch, *wij lezen* (we read) but *ik lees* (I read), as consonants in final positions in Dutch are devoiced. In cross-linguistic research it is thus important to realise that languages differ from another in more than one dimension of orthographic depth, as is also the case with subdimensions of phonological transparency (Schmalz et al., 2015): completeness, complexity, and transparency (or consistency). Incompleteness refers to the extent to which sublexical correspondences are complete. Examples in English are heterophonic homographs such as *wind*, for which the context is needed to disambiguate the meaning. In Hebrew, vowels are not represented, and therefore many words can have several different pronunciations (and meanings). Consequently, pointed Hebrew, in which the vowels are represented, is easier to acquire than nonpointed Hebrew, which contains only consonants (Frost, 1994). Complexity is defined as multiletter graphemes and/or context-sensitive pronunciations that occur in a particular language. For example, multiletter graphemes such as *sj*, *sh*, and *ng* make Danish relatively harder to learn (Elbro, 2005).

In the present article we focus on the consistency of grapheme-to-phoneme correspondences, that is, the number and frequency of the different ways a grapheme can be pronounced in a particular orthography. Tests of effects of one or more aspects of orthographic depth have almost always compared English, an outlier orthography (Share, 2008), with Dutch, German, Greek, Portuguese, and/or French orthographies with designs that lacked full control of all dimensions of orthographic depth involved. In the present research we compare Danish with Swedish, orthographies that differ in the consistency of the grapheme-to-phoneme correspondences, whereas all other aspects of orthographic depth are controlled.

Orthographic learning ability

Hogaboam and Perfetti (1978) presented nonwords either orally or in printed form. Nonwords in printed form were subsequently read faster than nonwords presented in spoken form. This finding suggests that better recognition after reading than after listening is due to phonological recoding, which led Share (1995) to propose that orthographic knowledge, that is, knowledge of the letters and the order of the letters in a word, is word specific and is committed to memory through phonological recoding of the word. Phonological recoding serves as a self-teaching device enabling the beginning reader to gradually shift from applying grapheme–phoneme conversion rules to fast retrieval of word pronunciations. Developing properly structured lexical entries (Henderson, 1982) and learning how to efficiently use the direct route of visual-orthographic look-up is called “orthographic learning” (Share, 1995).

Share (2004) found that beginning readers in Grade 1 were able to almost perfectly decode pointed Hebrew novel words (as measured by sounding out the letters of the word). However, it was not until the third grade that children acquiring nonpointed Hebrew showed signs of orthographic learning, contrary to English children (Ehri & Saltmarsh, 1995) and Dutch children (Reitsma, 1983), who become very early sensitive to orthographic features. Therefore, Share (2004) concluded that the time course of acquiring orthographic learning ability may well differ across languages of different orthographic depth.

Cross-linguistic research on orthographic depth and orthographic learning ability

Seymour, Aro, and Erskine (2003) compared how accurately and quickly first graders in 13 European orthographies could read. As predicted by the orthographic depth hypothesis, they found that readers of shallow orthographies, like Finnish, Greek, Italian, and Spanish, were able to

read accurately and quickly by the end of the first grade (more than 90% of high-frequency words correct within 1.5 s), whereas readers of deep orthographies—French, Portuguese, Danish, and English—were less accurate and slower.

Other evidence comes from the study by Ellis et al. (2004), who examined the effects of orthographic depth on reading acquisition in alphabetic, syllabic, and logographic scripts. Children between 6 and 15 years of age read aloud in transparent syllabic Japanese hiragana, alphabets of increasing orthographic depth (Albanian, Greek, English), and orthographically opaque Japanese kanji ideograms, with items being matched cross-linguistically for word frequency. Response accuracy, latency, and error types were analysed. Accuracy correlated with depth: Hiragana was read more accurately than, in turn, Albanian, Greek, English, and kanji. The deeper the orthography, the less latency was a function of word length, the greater the proportion of errors that were no responses, and the more the substantive errors tended to be whole-word substitutions rather than nonword mispronunciations. Orthographic depth thus affects both rate and strategy of reading.

Researchers have also looked at how phonological skills, verbal short-term memory, and other cognitive skills differentially underpin reading skill across orthographies varying in depth (Georgiou, Parrila, Kirby, & Stephenson, 2008). However, although it has been known for a long time that orthographic learning ability accounts for unique variance in reading ability beyond effects of phonological skills and rapid naming (Cunningham, Perry, Stanovich, & Share, 2002), there is no research to date focusing on how orthographic learning ability develops across orthographies differing in orthographic depth. In addition, effects of similarities between the native and the foreign language on the ease with which a second language (L2) is acquired have been examined (e.g., Ellis & Beaton, 1993; Geva & Siegel, 2000); however, these studies have not been conducted in the context of orthographic learning. The current study seeks to fill this gap in our understanding of how orthographic learning ability develops across orthographies that differ in orthographic depth.

Cross-linguistic comparisons

In conducting cross-linguistic research it is essential that assessment materials, which are necessarily different, are nevertheless unbiased. For example, Seymour et al. (2003) used nonwords to investigate the effect of syllabic complexity to control for differences in familiarity with real words. Assuming that numerals occur equally frequently across languages, Wimmer and Goswami (1994) constructed number-based nonwords to compare the processes of learning to read in deep English with shallow German. For German, the nonword *vechs* was derived from *vier* (four) and *sechs* (six), whereas an equivalent English nonword such as *tix* was made up from *ten* and *six*. To balance the meaning of the stimuli, Thorstad (1991) used translation equivalents. Landerl, Wimmer, and Frith (1997) took this a step further in order to control for word form and used words of the same origin (Pflug—plough), as did Ziegler, Perry, Jacobs, and Braun (2001). Seymour et al. (2003) also used high-frequency materials to make sure that the opportunity to learn these words was equal across languages.

However, nonword reading does not necessarily carry over to real-word reading. Translation equivalents may well differ in frequency and usage across languages, and high-frequency words do not form a representative sample of a language. For these reasons, Ellis and Hooper (2001) proposed a frequency-stratified random selection procedure. They sorted for English and Welsh representative sets of 1 million written words in decreasing frequency order. Then the sets were split up into hundred log₁₀ strata. From each stratum of each set, one word was then randomly selected. This resulted in two word lists—one English, one Welsh—each consisting of 100 words that were balanced with respect to written frequency yet varied along other dimensions. Ellis et al. (2004) contended that it is necessary to control only the opportunity to learn words of a given language, which can best be done by controlling for frequency.

We extended the Ellis and Hooper method by randomly selecting a cognate from each frequency stratum of Danish and Swedish counts. The Scandinavian languages share very many word forms due to their common Nordic roots and common imports from other Germanic languages. Because

cognates occur across all frequency strata, the thus obtained stimulus sets are perfectly representative of the Danish and Swedish languages. By selecting cognates, not only meanings were balanced (we obviously did not select false friends, that is, words with the same form but a different meaning) but more importantly, syllable complexity and other phonological and morphological features that otherwise could create biased stimulus sets were fully controlled. Moreover, because of the many cognates that these two languages share outside the ones we chose for the test materials, the neighbourhood size and density is far more controlled than is possible with other language combinations (Marinus, Nation, & De Jong, 2015). In the appendix we present the English words we used in the current project ordered from frequent to infrequent with their Danish–Swedish translation equivalents. The English words were randomly selected from 40 frequency bands. For only three out of 40 English words could no Danish–Swedish cognate be found. This shows that Danish and Swedish share very many cognates. It is very unlikely that noncognate words would make much of a difference in neighbourhood size and density, as there exist very few noncognate words.

Danish and Swedish phonology and orthography

Danish and Swedish belong to the North Germanic languages and are descendants of Old East Norse. By the end of the 11th century, Danish began to diverge from Swedish because spelling reforms in Denmark started to lag behind the rapidly changing pronunciation of Danish. Additional orthographic complexities in Danish came about as a result of the import of loan words in their foreign spellings—such as the French *bureau(x)*, which is spelled transparently in Swedish as *byrå(er)*, but not consistently, as *exams* is *eksaminer* in Danish and *examina* in Swedish. In Swedish, the pronunciation of words has not changed that much. The translation of the Bible by Gustav Vasa in 1541 played a major role in the standardisation of written Swedish, although it was not until the spelling reform of 1906 that Swedish orthography was finally stabilized in order to make the growing public school system accessible.

This historic evidence is supplemented with empirical findings. For example, Doetjes and Gooskens (2009) assessed the orthographic and phonetic distance between Swedish and Danish, using the Levenshtein algorithm (Heeringa, 2004). The orthographic distance was 24%, whereas the phonetic distance was 53%. The fact that the pronunciation is less similar than the spelling allows for the inference that Danish has a deeper orthography than Swedish. Other evidence comes from formal linguistic analyses, for example, phoneme–grapheme consistencies of Danish are even lower than American English—.672 for vowels and .750 for consonants (Nielsen & Juul, 2016)—whereas grapheme–phoneme consistencies are .378 for vowels and .713 for consonants (Juul, 2008).

Confounding factors in contrasting Danish with Swedish

Differences in reading and spelling achievement across languages can obviously also be caused by other factors than orthographic depth of the languages, such as cultural and educational aspects. Because of the very similar political, economic, and social structures in the Scandinavian countries, and a very similar comprehensive school system (Wiborg, 2004), we have no reason to believe that differences in performance on reading and cognitive tasks in the current study are caused by differences in preschool and school education across Denmark and Sweden.

In contrast to Swedish, spoken Danish definitely lacks sound distinctness. According to Kuhl (2004), this means that the sound distributions of Danish are relatively flat without sharp boundaries between them, so that it takes longer for a child to infer the prototypical sounds of Danish. As a consequence, it is much harder to pick up the phonotactic patterns of Danish. This could explain the finding by Wehberg (2007) that 2½-year-old Danish children lagged 2–3 months behind American children in active and passive vocabulary. In addition, Elbro, Borstrøm, and Petersen (1998) showed that distinctness of phonological representations is a strong predictor of phonological recoding skill. Therefore it can be hypothesised that Danish students lag behind Swedish students in phonological

memory and vocabulary. Phonological memory is taxed more if the sounds of the language are indistinct and vocabulary thus does not grow as fast.

Orthographic learning as a generic skill

Orthographic knowledge is, according to Share (1995), acquired through successful phonological recoding, which works as a self-teaching mechanism. In this way not only declarative knowledge is acquired (item-specific orthographic knowledge) but also procedural knowledge, when the child extracts regularities of the language, that is, learns what is legal and not legal in the orthography at hand. Once these rules are learnt, reading can further be automatized.

More recently, Frost, Siegelman, Narkiss, and Afek (2013) proposed that individual differences in both first language (L1) and L2 learning reflect a general capacity for statistical learning, that is, a process of picking up and implicitly assimilating the statistical properties of a linguistic environment. On the basis of this theory we suggest that orthographic learning ability is a generic skill for the processing of print. Furthermore, if orthographic learning ability can be more easily acquired in a shallow orthography than in an opaque orthography, not only declarative knowledge but also procedural knowledge of L2 can be more efficiently built up by learners of Swedish in comparison to learners of Danish.

Hypotheses

With the self-teaching hypothesis in mind, we hypothesise that orthographic learning ability develops more efficiently in a shallow orthography than in a deep orthography, because phonological recoding can be applied more easily in a shallow orthography. If grapheme–phoneme correspondences are less consistent as they are in deep orthographies, they are harder to master than in shallow orthographies in which they are more consistent.

The second hypothesis is that orthographic learning is a generic skill and can be expanded to a foreign language, especially if this language is also acquired through print. It is expected that children who learn a shallow orthography will outperform their counterparts in foreign language acquisition.

Method

Participants

Danish participants were 48 third, fourth, and fifth graders, whereas in Sweden 62 third, fourth, and fifth graders took part. Children with diagnosed learning difficulties, one boy who had lived in the United Kingdom (on the border with Wales), and one immigrant (traveller) child who had not attended preschool and primary school on a regular basis were eliminated from the samples, according to exclusion criteria set up before data collection started. The schools from which we recruited were commensurable with respect to achievement on national tests for reading and arithmetic and had comparable catchment areas with respect to socioeconomic backgrounds, as registers of national agencies¹ indicated.

Materials²

Vocabulary

Eighty words and 20 nonwords were taken from the X_Lex test (Meara, 1994) to measure the pupils' written English vocabulary. The items were presented on MacBook computers (programmed with SuperLab 4.0.7b; Abboud, Schmitz, & Zeitlin, 2008) in a different random order for each participant.

¹Danish source: Aabenraa municipality, School quality report 2009/2010 (http://www.aabenraa.dk/files/Aabenraa/Filarkiv/Borger/Skole_uddannelse/Kvalitetsrapport%20skoleomr%C3%A5det/Kvalitetsrapporten%20skolerne%202009-10.pdf). Swedish source: The Swedish National Agency for Education, Statistics Office (http://sir.is.skolverket.se/apex/ris.rapp_param_amnesprov.ap5).

The pupils were required to press the green key if they were absolutely sure that they knew the meaning of the word and to press the red key if they did not know the meaning or were uncertain. D-prime was analysed (<http://www.linguistics.ucla.edu/faciliti/facilities/statistics/dprime.htm>). The L1 vocabulary tests were constructed and analysed in the same way. Frequencies of a Danish word count (Korpus, 2000; <http://korpus.dsl.dk>) and of the Swedish Academy Word Count (<http://www.saob.se>) were converted into frequency per million and split up in 50 $\log_{10}$ frequency bands. Forty cognates were then selected from each of the 40 least frequent strata. Twenty nonwords were created by selecting a cognate from every second frequency band, and then by changing one letter of that word, so that it became a nonword in both languages. The L1 and L2 vocabulary tests had homogeneity reliabilities of .90 and .94, respectively. One may argue that with this test format only passive and not active vocabulary is assessed, as the students are not required to give the meaning of the word. However, active vocabulary and other (foreign) language skills rest on passive vocabulary, and if a student does not recognise a string of letters as a word, he will not be able to do much with that word (Meara, 1994).

Phonological working memory

A nonword repetition task was used, which consisted of 16 Welsh words pronounced by a native Welsh speaker. The participant was presented with each word twice and was asked to repeat it after the second time. An assessor scored the number of correctly repeated syllables. We used Welsh words under the assumption that these words do not bias either of the samples. Furthermore, nonword repetition tasks with unfamiliar sound structures such as Welsh are less influenced by long-term memory representations and therefore could be considered to be purer measures of phonological short-term memory (Baddeley, 2012). The homogeneity reliability of this test was .72.

Orthographic learning

In this test, originally developed by Thate (1998), participants are shown slides with a picture and a slogan containing the brand name of the pictured item in capital letters. The brand name is always a nonword. The current version included 29 novel phonotactically legal brand names, of which, in a fixed random order, seven were shown once, eight shown twice, seven shown thrice, and seven shown four times. The score was the total number of spellings correctly recognised immediately after the slides were presented. Each slide was presented for 5 s. The homogeneity reliability was .69. We did not opt for a task in which novel words are embedded in text, because a short task with isolated novel words takes less time to administer and is sufficiently fit for purpose. The strength of this task is that it dynamically measures orthographic learning ability, whereby effects of reading and spelling experience with real words is minimised. A phonological foil for the brand names, which are phonotactically legal in both Danish and Swedish, albeit a bit uncommon as words but not as (international) brand names, was created by replacing a letter or letter cluster by a letter/letter cluster that has an almost similar sound (e.g., s/z, ss/zz, m/n, f/v, b/p; in North Germanic languages as Danish and Swedish such differences are minimal, or not even existing; e.g., the zz in *intermezzo* is pronounced as /s/) or similar sound (e.g., ch/g, c/s, c/k, au/ou, final t/d, oe/ou, making these foils homophonic). Other ways of creating sound-confusable foils included leaving out silent r, beginning e/i and d/p, and final ol/el, on/un, es/us. Orthographic foils were constructed by replacing a single letter by another letter with which it is visually confusable (e.g., I/L, C/K, A/O, T/L, H/K, T/F, P/B, V/W, UU/OO; all stimuli were presented in capital letters). Other manipulations included the reversal of two letters and, in one case, dropping the R from the cluster STR. Another reason to use words that were legal but uncommon was to preserve the dynamic character of the task: Individual differences in the number previously acquired words should be controlled, because these may depend on other factors. As at the time we developed this task the effects of context were not yet examined and we sought to simplify the task while keeping it ecologically valid, that is, the requirements

²An example of consistency of the grapheme *a* and the most frequent multiletter graphemes in Danish can be found in Appendix II. In Appendix III to VI the test items of all tasks are presented. Appendices II to VI can be found in the supplementary materials.

for the task include (a) the learning of the concept (novel word DIKS “means” BIKE), (b) the learning of its pronunciation (DIKS is pronounced as /d//i//k//s/), and (c) the learning of the spelling (DIKS). The score, total number of brand names correctly recognised, therefore stands for the overall quality of the orthographic representations built up after one, two, three, or four presentations. Some of these representations may be stronger than others, due to proper representations at semantic and phonological level. In case phonological representations are not so strong, students might be inclined to go for a phonological foil; if visual-orthographic representations are weak, students may go for the orthographic foil.

Visual word familiarity

The Wordchains test (Miller-Guron, 1999) was used to assess visual word familiarity in L2. The participants were requested to split as many word chains (sandcoffeeblue should be split into sand, coffee, and blue) as they could within 3 min. The standardised Norwegian version of the Wordchains test (Høien & Tønnesen, 1997) was used to construct the Danish and Swedish versions by replacing each word of this version by the Danish and Swedish cognate, respectively. Split-half reliabilities of .94 and .93 were found for L1 and L2 visual word familiarity, respectively.

Reading accuracy and fluency

Words were presented together with a beep on the computer. A Cedrus SV-1 voice key was used to register the latencies. The participants were instructed to read aloud the word as fast and accurate as (s) he could. The experimenter scored accuracy online. The number of correctly read words was counted to assess reading aloud accuracy. Mean $\log_{10}$ transformed latencies of correctly read words were taken as the score for reading aloud fluency. The English reading test comprised 40 words taken from every odd stratum from the 21st to the 99th stratum of a 100-word list with decreasing frequency (Van Daal, Spencer, Cashman, & Hoxhallari, 2003). For the L1 reading tests, cognates (different to those selected for the vocabulary tests) were selected from each of the lowest 40 $\log_{10}$ frequency bands of the Danish and the Swedish word counts. Five high-frequency words were used as practice items in both the L1 and the English tests. Reliabilities of .91 and .64 were found for L1 reading aloud fluency and L2 reading aloud fluency, respectively. Testing was concluded after five consecutive errors.

Spelling

All words of the L1 reading test and the first 16 words of the L2 reading tests were also used in the spelling tests administered 2 weeks before the reading tests. A MP3 file was played, on which the word to be spelled was pronounced, followed by a sentence in which it was used. It was then repeated once more. The scores for L1 and L2 spelling were the number of words correctly spelled, with reliabilities of .83 and .91, respectively.

All computer-based tests were audio-recorded so that when it was suspected that there was a technical difficulty with the voice key highlighted by the experimenter, or when the experimenter was uncertain how to score a response from the participant (also highlighted), responses could be scored afterward using the recordings.

Procedure

Ethical approval was obtained from the universities with which the authors were affiliated. The parents gave active consent for their children to take part. The classroom tests were administered over two 30-min sessions with a short break in between. L1 and L2 spelling and visual word familiarity were administered before the break and orthographic learning after the break. L1 and L2 reading, vocabulary, and phonological working memory task were administered in one individual test session, 2 weeks after the classroom sessions.

Analysis

In the current study, we drew commensurable samples from third, fourth, and fifth graders across Sweden and Denmark and compared the samples on vocabulary; phonological working memory; orthographic learning ability; and, for L1 and L2, visual word familiarity, reading aloud accuracy, reading aloud fluency, and spelling. To test if orthographic learning ability explains differences in L1 and L2 achievements over and above vocabulary and phonological working memory, Roy–Bargmann step-down tests were used (Roy & Bargmann, 1958). For each variable in the ordered list of independent variables it is first tested whether that variable (e.g., vocabulary) affects differences between subjects on the dependent variable (e.g., spelling). Then the variable is entered as a covariate to examine the effect of the next variable (e.g., phonological memory) on the dependent variable. If the last independent variable as a covariate leaves a difference on the dependent variable, there must be other (unknown, not measured) factors at work. If the last independent variable completely explains differences on the dependent variable, there are no other factors at work except the previously entered covariates and the independent variable in so far as tests were significant. Roy–Bargmann step-down tests are confirmatory tests. The theoretical model that we test is that vocabulary, phonological memory, and orthographic learning ability have, in that order, an effect on reading, spelling, and visual word familiarity. We did this to keep in line with Cunningham et al. (2002), who entered orthographic learning ability as the last independent variable in their regression analyses.

Results

Covariates

In Table 1 means, standard deviations, number of respondents, and 95% confidence intervals are presented for covariates and L1 and L2 assessments.

The Swedish participants had a larger L1 vocabulary than their Danish counterparts, $F = 7.634$, $p = .007$, $\eta^2 = .066$. They also had a better phonological working memory, $F = 36.322$, $p < .001$, $\eta^2 = .251$, and were better at orthographic learning, $F = 10.277$, $p = .002$, $\eta^2 = .087$. When L2 vocabulary was entered in the analysis as the first independent variable, on which the Swedish students were better than the Danish ($F = 6.753$, $p = .011$, $\eta^2 = .059$), differences on phonological working memory and orthographic learning did not change, $F = 36.322$, $p = .001$, $\eta^2 = .252$, and $F = 10.276$, $p = .002$, $\eta^2 = .087$, respectively.

Table 1. Descriptive statistics for covariates, L1, and L2 assessments per subsample.

	Danish				Swedish			
	<i>M</i>	<i>SD</i>	<i>n</i>	95% CI	<i>M</i>	<i>SD</i>	<i>n</i>	95% CI
Phonological Working Memory	60.50	5.62	48	[58.87, 62.13]	66.19	4.17	62	[65.14, 67.24]
Orthographic Learning	13.38	5.15	48	[11.88, 14.87]	16.77	5.19	62	[15.50, 18.05]
Vocabulary L1	1.69	.72	48	[1.47, 1.89]	2.09	.83	62	[1.88, 2.29]
Vocabulary L2	-.12	0.94	48	[-.39, .15]	.32	0.93	62	[-.09, .55]
L1 Visual Word Familiarity	25.69	9.60	48	[22.90, 28.48]	35.77	12.26	62	[32.76, 38.79]
L1 Reading Accuracy	37.10	3.28	48	[36.15, 38.06]	38.81	1.62	61	[38.40, 39.22]
L1 Reading Fluency	3.06	0.12	48	[3.02, 3.09]	2.94	0.07	61	[2.92, 2.95]
L1 Spelling	26.25	7.18	48	[24.16, 28.34]	32.53	4.63	62	[31.39, 33.67]
L2 Vocabulary	-.12	0.94	48	[-.39, .15]	.32	0.93	62	[-.09, .55]
L2 Visual Word Familiarity	16.06	9.51	47	[13.27, 18.85]	22.05	10.75	62	[19.40, 24.69]
L2 Reading Accuracy	26.33	8.53	48	[23.86, 28.81]	27.27	5.91	61	[25.77, 28.78]
L2 Reading Fluency	3.11	0.13	41	[3.06, 3.15]	3.06	.093	62	[3.04, 3.09]
L2 Spelling	5.40	3.49	40	[3.87, 5.88]	7.52	3.87	60	[6.54, 8.46]

Note. L1 = first language; L2 = second language; CI = confidence interval.

Table 2. L1 assessments: Multivariate analysis of variance results.

Multivariate Test	Univariate Tests				Roy-Bargmann Step-Down Tests	
	Variables	<i>F</i>	<i>p</i>	η^2	<i>df</i>	<i>p</i>
$\lambda = .693$, $F(3, 106) = 15.651$, $p < .001$	VOC	7.634	.007	.066	1, 108	.007
	PWM	36.322	<.001	.251	1, 107	<.001
	OL	10.277	.002	.087	1, 106	.047
$\lambda = .656$, $F(4, 104) = 13.640$, $p < .001$	VOC	7.999	.006	.070	1, 107	.006
	PWM	37.195	<.001	.258	1, 106	<.001
	OL	10.670	.001	.091	1, 105	.041
$\lambda = .554$, $F(5, 103) = 16.531$, $p < .001$	Reading Accuracy	12.281	.001	.103	1, 104	.041
	VOC	7.999	.006	.070	1, 107	.006
	PWM	37.195	<.001	.258	1, 106	<.001
	OL	10.671	.001	.091	1, 105	.041
	Reading Fluency	12.281	.001	.103	1, 104	.041
$\lambda = .632$, $F(4, 105) = 15.278$, $p < .001$	Reading Fluency	39.720	<.001	.271	1, 103	<.001
	VOC	7.634	.007	.066	1, 108	.006
	PWM	36.322	<.001	.252	1, 107	<.001
	OL	10.676	.002	.087	1, 106	.041
$\lambda = .678$, $F(4, 105) = 12.466$, $p < .001$	Spelling	29.240	<.001	.213	1, 105	.041
	VOC	7.634	.007	.066	1, 108	.007
	PWM	36.322	<.001	.252	1, 107	<.001
	OL	10.276	.002	.087	1, 106	.047
	VWF	19.178	<.001	.150	1, 105	.130

Note. VOC = Vocabulary first language; PWM = Phonological Working Memory; OL = Orthographic Learning; VWF = Visual Word Familiarity.

Table 3. Second-language assessments: Multivariate analysis of variance results.

Multivariate Test	Univariate Tests				Roy-Bargmann Step-Down Tests	
	Variables	<i>F</i>	<i>p</i>	η^2	<i>df</i>	<i>p</i>
$\lambda = .691$, $F(3, 106) = 15.776$, $p < .001$	VOC	6.753	.011	.059	1, 108	.011
	PWM	36.322	<.001	.252	1, 107	<.001
	OL	10.276	.002	.082	1, 106	.046
$\lambda = .666$, $F(4, 104) = 13.060$, $p < .001$	VOC	6.750	.011	.059	1, 107	.011
	PWM	37.195	<.001	.258	1, 106	<.001
	OL	10.671	.001	.091	1, 105	.038
$\lambda = .688$, $F(4, 98) = 11.103$, $p < .001$	Reading Accuracy	<1	.550	.003	1, 104	.104
	VOC	2.578	.111	.025	1, 101	.111
	PWM	37.644	<.001	.272	1, 100	<.001
	OL	7.699	.007	.071	1, 99	.064
$\lambda = .687$, $F(4, 105) = 11.944$, $p < .001$	Reading Fluency	3.424	.067	.033	1, 98	.327
	VOC	6.753	.011	.059	1, 108	.011
	PWM	36.322	<.001	.252	1, 107	<.001
	OL	10.277	.002	.087	1, 106	.038
$\lambda = .689$, $F(4, 104) = 11.720$, $p < .001$	Spelling	12.979	<.001	.107	1, 105	.104
	VOC	6.925	.010	.061	1, 107	.010
	PWM	35.697	<.001	.250	1, 106	<.001
	OL	10.789	.001	.092	1, 105	.039
	VWF	9.173	.003	.079	1, 104	.867

Note. VOC = Vocabulary second language; PWM = Phonological Working Memory; OL = Orthographic Learning; VWF = Visual Word Familiarity.

L1 assessments

In Table 2 means, standard deviations, number of respondents, and 95% confidence intervals are presented for L1 assessments.

With respect to L1 (Table 2), Swedish students performed better than Danish students on fluency of reading aloud, spelling, and visual word familiarity, $F = 39.720$, $p < .001$, $\eta^2 = .271$ (after

differences on accuracy were balanced out); $F = 29.240$, $p < .001$, $\eta^2 = .213$; $F = 19.178$, $p < .001$, $\eta^2 = .150$; respectively, and on accuracy of reading aloud, $F = 12.281$, $p = .001$, $\eta^2 = .103$.

Once vocabulary, phonological working memory, and orthographic learning were accounted for, the samples did not differ anymore visual word familiarity, though Swedish children were still better spellers and more fluent and accurate at reading than Danish children, as can be inferred from the Roy–Bargmann step-down tests.

L2 assessments

With respect to L2 (Table 3), Swedish students performed at the same level as Danish students on accuracy and fluency of reading aloud ($F < 1$, and $F = 3.424$, $p = .067$, $\eta^2 = .033$, respectively). However, on spelling and visual word familiarity Swedish students did better than Danish students ($F = 12.979$, $p < .001$, $\eta^2 = .107$, and $F = 9.173$, $p = .003$, $\eta^2 = .079$, respectively).

Once vocabulary, phonological working memory, and orthographic learning were accounted for, the samples did not differ on reading accuracy and fluency, though Swedish children were still better spellers and more familiar with English word forms, as the Roy–Bargmann step-down tests show.

Discussion

The current research set out to look at whether orthographic learning develops less efficiently in a deep orthography (Danish) as compared to a shallow orthography (Swedish). We used cognates to examine the effects of the consistency of grapheme to phoneme correspondences in order to rule out other confounding factors. We also examined whether this would have repercussions for L1 and L2 literacy development (reading, spelling, and visual word familiarity). In the research, samples were drawn from countries with similar educational and cultural backgrounds, which differed on written vocabulary and phonological working memory. The samples were retrospectively balanced in a statistical way before the effect of orthographic learning ability was examined. At the same time, the fairest possible cross-linguistic literacy tests were used, whereas orthographic learning ability was assessed with a dynamic learning measure. The essential findings were that (a) Swedish children have better orthographic learning ability than their Danish counterparts, and (b) orthographic learning explains over and above vocabulary and phonological working memory the better performance of Swedish children in comparison with Danish children on L1 reading accuracy and fluency, spelling, and visual word familiarity.

However, on all of these variables other factors might explain the superiority of Swedish children over Danish children. We further found with respect to L2 learning, English as a foreign language, that (c) orthographic learning ability determines together with L2 written vocabulary and phonological working memory fully the differences in spelling and visual word familiarity of English. Children, who learn to read and spell in a shallow orthography, apparently transfer their orthographic learning skills to English: The orthographic representations are sufficiently stable for visual word familiarity and spelling tasks but not (yet) for reading accuracy and fluency tasks. These results fully support the orthographic depth hypothesis by showing that Danish and Swedish, two cousin languages, which differ in only consistency of grapheme-phoneme correspondences, differ in learnability. The results extend the findings by Seymour et al. (2003) by showing that differences in learnability between deep and shallow orthographies still exist beyond the foundation stages, as we examined children who had received reading instruction for a longer time.

The deep orthography and the indistinct sounds of Danish affect the accuracy and fluency of Danish children in isolated word reading. The disadvantage in fluency of isolated word reading for the Danish children in 1 hr of reading is estimated on the basis of the latencies found in this research to vary between 435 and 777 words, given that the L1 words were read between 248 and 153 msec slower by Danish children than by their Swedish counterparts. On the basis of research by Kim and Wagner (2015), who found that word decoding fluency correlates highly with text reading fluency, this could mean that the disadvantage keeps growing over time, which explains the findings of

international comparative studies that show that Danish adults perform less well than comparable adults from Sweden (Elley, 1992). This could mean that compensatory strategies may fail.

This is the first study to examine the role of orthographic depth of the L1 on learning a second, deep, orthography. On the basis of the present research, it is suggested that learning a shallow orthography first promotes not only the development of a larger vocabulary and better phonological working memory but also is also beneficial for acquiring orthographic learning skills; all three will support the acquisition of a second, deeper orthography. In a similar vein, Thorstad (1991) found that children taught with the Initial Teaching Alphabet, a set of letters with which regular English words can be deciphered, made more progress in learning to read than children who learnt to read with a traditional method, in which a mix of regular and irregular words were presented. It would be interesting to see (a) whether orthographic learning ability is a skill that has a reciprocal relationship with learning to read and spell, as is argued to be the case for phonological awareness (Castles & Coltheart, 2004) and (b) which cognitive skills underpin orthographic learning ability: a generic skill such as statistical learning as proposed by Frost et al. (2013), phonological working memory (Baddeley, 2012; Share, 1995), for which we found the largest effect in the present study as a covariate, or possibly also visual-spatial working memory (Pickering, Gathercole, Hall, & Lloyd, 2001), or paired-associate learning (e.g., Hulme, Goetz, Gooch, Adams, & Snowling, 2007). In deep orthographies, reliance on vocabulary might support orthographic learning ability (Tunmer & Chapman, 2012).

This research shows that children's language development is affected by the orthographic transparency of their L1. It is important that reading methods take account of this and compensate for the difficulties that some, if not all children, have in learning to read in deep orthographies, such as English, Danish, and Portuguese. It may be worthwhile to examine how, after having learnt the basics of reading through synthetic phonics, partial phonological recoding and orthographic learning can be boosted.

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Appendix

Danish and Swedish Translation equivalents of English reading and spelling stimuli

English Word	Frequency Stratum	Danish Translation Equivalent	Swedish Translation Equivalent	Remarks
never	21	aldrig	aldrig	
much	23	meget	mycket	
off	25	af	av	
against	27	mod	mot	
himself	29	selv	han själv	
night	31	nat	natt	
point	33	punkt	punkt	
number	35	antal	antal	
car	37	bil	bil	
less	39	mindre	mindre	
rest	41	resten	resten	
paper	43	papir	papper	
simple	45	enkel	enkel	
knows	47	ved	vet	
none	49	ingen	ingen	
price	51	pris	pris	
putting	53	sætter	sätter	infinitive; progressive form is much less used in Danish and Swedish
benefit	55	fordel	fördel	
African	57	afrikansk	afrikansk	
closely	59	nøje	nära	
painting	61	maleri	målning	noun
self	63	selv	själv	
helps	65	hjælper	hjälp	
passed	67	passerede	passerade	
appointment	69	udnævnelse	utnämning	
objectives	71	mål	mål	
mentally	73	mentalt	mentalt	
prey	75	bytte	byte	
woodland	77	skov	skog	
supplies	79	fornødenheder	förnödenheter	noun, plural
exams	81	eksaminer	examina	
racing	83	racing	racing	
disgrace	85	vanære	vanära	
outbreak	87	udbrud	utbrott	
medicines	89	mediciner	mediciner	
folder	91	folder	folder	
thanking	93	takkende	tackande	
misgivings	95	betænkeligheder	betänkligheter	
semantic	97	semantisk	semantisk	
discretionary	99	diskretionær	diskretionär	