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The Growth of Word and Pseudoword Reading Efficiency in Alphabetic Orthographies: Impact of Consistency

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Abstract

Word and pseudoword reading are related abilities that are fundamental to reading development in alphabetic orthographies. They are respectively assumed to index children's orthographic representations of *words* as acquired through the underlying 'self-teaching mechanism' of alphabetic *pseudoword* decoding. However, little is known about the concurrent growth trajectories of these skills in the early grades among children learning different alphabetic orthographies. In the present study, between- and within-group latent growth models of word and pseudoword reading efficiency were tested on data spanning first and second grade, from learners of the inconsistent English, and consistent Czech and Slovak orthographies. Several language-general patterns emerged. First, as expected, significant growth was observed for both skills in all languages. Second, growth was faster for word than pseudoword reading efficiency, and accordingly, strong lexicality effects that increased over time were obtained across languages. Language-specific patterns were also found. In line with predictions about the *costs* to learning of lower consistency orthographies, readers of English experienced relatively slower growth on both reading skills. However, their lag was smaller, and evident only at the latter two time points for word reading. In contrast, on pseudoword reading, the English group performed considerably less well than their Czech and Slovak peers at every time point. Thus, weak decoding skills were the main contributor to the larger lexicality effects of the English group. These findings are considered within the frame of recent theorizing about the effect of orthographic consistency on decoding as a self-teaching mechanism in alphabetic reading acquisition.

Introduction

Measures of word and pseudoword reading efficiency are two ubiquitous indicators of *fluent* and *accurate* word-level reading ability in alphabetic orthographies. They have been contrasted in many languages, in experimental and cross-sectional studies seeking to uncover the contribution of each skill to typical and atypical reading development. Yet, despite their widespread use in reading research, and, the strong assumptions about their utility as indices of reading proficiency (fluent word reading) and risk of reading failure (deficient pseudoword reading), several aspects of their development remain unexplored. In particular, longitudinal studies are lacking that examine concurrently how each skill grows in relation to the other, and, how the consistency of letter-sound mappings in the orthography being learned might influence their respective growth processes. To shed light on these questions, the present study used latent growth modelling to investigate the growth of word and pseudoword reading efficiency from first to second grade, among learners of the inconsistent English orthography and learners of the relatively consistent orthographies of Czech and Slovak.

Background

Word reading efficiency refers to fluent and accurate reading of words; it is usually assessed under time pressure, and is an important contributor to reading comprehension skill (e.g., Perfetti, 2007). In alphabetic orthographies, efficient word reading arises most reliably from children’s primary ability to *decode* printed words, that is, the ability to associate letters (graphemes) more or less sequentially with their corresponding sounds (phonemes), and to blend the sounds into accurate word pronunciations. Share’s (1995) *self-teaching hypothesis* emphasizes decoding as the learning mechanism that underlies early alphabetic reading, and proposes that, as children successfully apply the phonological (i.e., grapho-phonemic) recoding procedure to newly encountered words, they build up word-specific orthographic representations. Repeated decodings of specific words incrementally refine and strengthen their orthographic representations, and consequently facilitate efficient word recognition (e.g., Cunningham, Perry, Stanovich, & Share, 2002; Ehri, 2005, 2015). Thus, the decoding process is understood to be the ‘sine qua non’ driver of robust orthographic representations and of efficient word reading skills (Share, 1995).

Pseudoword reading (also referred to as nonword reading) is a widely used measure of decoding ability. Written pseudowords are word-like in their graphotactic and phonotactic structures; however, having neither lexical identity nor meaning, they present as novel items that can only be read by the phonological recoding process. Within the self-teaching hypothesis framework, and other compatible theories of reading development (e.g., Ehri, 2005; Perfetti & Hart, 2002), pseudoword reading tasks are used to assess children’s decoding *and* orthographic learning skills (e.g., de Jong & Messbauer, 2011; Share, 2004). Moreover, they are widely used to diagnose the *nonword reading deficit* (i.e., a phonological processing deficit) in dyslexia (e.g., Herrmann, Matyas, & Pratt, 2006; Rack, Snowling, & Olson, 1992).

Comparisons of word versus pseudoword performance on tasks of reading aloud typically show an advantage in favor of word reading accuracy and/or speed, the *lexicality effect*. In development, the emergence of the word reading advantage is thought to indicate that word spellings have been lexicalized to some extent, that is, stored in memory in connection to an existing lexical representation (e.g., Ehri, 2015). While questions about the exact nature of these representations and how they are accessed remain hotly debated (e.g., see Rayner & Reichle, 2010), they are tangential to our primary focus on the rate and pattern of growth of the lexicality effect itself.

The lexicality effect has been reported in a large number of studies with child and adult readers, skilled and less skilled, in many languages with alphabetic orthographies (e.g., Adelman, Sabatos-DeVito, Marquis, & Estes 2014; Sprenger-Charolles, Colé, & Serniclaes, 2006, ch. 2). Such studies show that its strength can be modulated by a variety of factors, some of which are inherent to the participant, and others to properties of the stimulus materials. Important participant variables are age and reading ability (which, in turn, may be influenced by various cognitive factors, most typically phonological and/or grapho-phonemic processing efficiency) (e.g., Rack et al., 1992; Van den Broeck, Geudens, & van den Bos, 2010). The item-level variables are numerous, but prominent among them are word frequency, item length, and orthographic consistency (i.e., the extent to which letters and sounds of printed words have one-to-one mappings) (Adelman et al., 2014; Rahbari & Sénéchal, 2010). In the present study, the attribute of central interest was orthographic consistency.

Alphabetic orthographies vary in terms of their system-wide consistency, and available estimates show the English orthography to be the least consistent, while others such as Czech, Slovak, and Spanish are relatively highly consistent (e.g., Caravolas & Samara, 2015). Within orthographies, a number of factors may produce grapho-phonemic mapping (i.e., letter-sound) inconsistency, including the extent to which they encode morphology, the frequency and recency of spelling reform in the language (orthographies that rarely undergo reform tend to contain more ‘irregular’ and ‘exception’ spellings reflecting archaic word pronunciations), and, the degree of homophony in the language (see Kessler & Treiman, 2015). Although some types of inconsistency (e.g., morphological encoding) may eventually provide insights and certain advantages for the skilled reader/writer (e.g., Seidenberg, 2011), for the typical novice reader, grapho-phonemic inconsistency is likely to present an obstacle to learning, regardless of its origins.

One well-documented effect of orthographic consistency is its impact on the rate of word-level reading growth: readers of more consistent orthographies learn to read more quickly than readers of less consistent orthographies (e.g., Caravolas, Lervåg, Defior, Seidlová Málková,

& Hulme, 2013; Seymour, Aro, & Erskine, 2003). However, the influence of orthographic consistency on the development of the lexicality effect is less clear. While no developmental, language-general theory has focused specifically on the growth of these dual reading processes, two theories have bearing on this issue. The *psycholinguistic grain size theory* (Ziegler & Goswami, 2005) proposes that in consistent orthographies, readers can derive pronunciations reliably using small-grain letter-sound mapping strategies whether decoding words or pseudowords. In inconsistent orthographies, small-grain size decoding strategies--while preferred for pseudoword reading--, are deemed less efficient for word reading, and are therefore assumed to be supplemented by larger grain size mapping strategies (e.g., syllables, rimes) that are salient in the spoken and written language. Extrapolating from this hypothesis, readers of consistent orthographies should benefit little from the lexical status of words—resulting in smaller lexicality effects; in contrast, the preference for different mapping processes in word and pseudoword reading among learners of inconsistent orthographies should result in larger lexicality effects. Along similar lines, the recent *decoding stagnation hypothesis*, proposed by Van den Broeck and Geudens (2012) in the context of their work on the nonword reading deficit in dyslexia, predicts larger lexicality effects for readers of inconsistent orthographies than consistent ones, but also, that pseudoword decoding should undergo gradual deceleration in growth specifically in inconsistent orthographies like English. This is because learners of the latter systems should increasingly draw on their word-specific orthographic knowledge when reading words, and with decreasing encounters of novel word/pseudoword items, they exercise their phonological recoding skills less frequently. In relatively consistent orthographies, the de-emphasis of phonological recoding in word reading should be less pronounced, resulting in relatively faster growth of pseudoword reading (no stagnation), and a smaller lexicality effect.

In line with the above theoretical predictions, several cross-linguistic studies have reported larger lexicality effects for readers of English than those of a variety of more consistent orthographies, and this seemed to be driven by English readers' disproportionately worse performance on pseudoword decoding (e.g., Landerl, Wimmer, & Frith, 1997; Patel, Snowling & de Jong, 2004; Seymour et al., 2003; Wimmer & Aro, 2003). However, it is difficult to generalize from these studies because most have used cross-sectional designs and combined participant- and stimulus-based factors, language groups, and research methodologies in myriad different ways. Moreover, they typically calculated the lexicality effect on the basis of raw score differences rather than standardized differences that take sample size and individual variation into account. Raw score effects may be misleading because English readers may show greater variation in both word and pseudoword reading than readers of more consistent orthographies, in particular when the consistent-orthography groups show ceiling effects in accuracy, as is often the case. In one of the few single-language studies investigating the development of the lexicality effect, Rahbari and Sénéchal (2010) contrasted first to fourth graders' reading efficiency of transparent (consistent) and opaque (inconsistent) words, and pseudowords in the relatively consistent Farsi orthography. Taking the view that successful reading experience drives the lexicalization of printed words, which in turn facilitates word recognition, these authors predicted that children would demonstrate lexicality effects of increasing magnitude from second grade onward for words with the most transparent mappings, because transparency should accelerate the establishment of lexicalized representations. On the other hand, they predicted no lexicality effects in the primary grades for words that had opaque letter-sound mappings because the orthographic representations for these should be more slowly acquired. Notably, Rahbari and Sénéchal's predictions did not include assumptions about children's strategic changes in grain-size mapping as a function of letter-sound consistency. Both predictions were borne out by the data, and their finding of no lexicality effect for opaque words until adulthood seemingly contradicted the general assumption of larger lexicality effects in less consistent orthographies. Despite such mixed findings, the empirical evidence to date suggests that language-specific differences are likely to emerge in the development of the lexicality effect, and that these may be driven to a large extent by differences in orthographic consistency.

A Study of Word and Pseudoword Reading Growth in Three Orthographies

The above empirical studies also highlight the fact that to better understand the growth of word and pseudoword reading skills and the influence of orthographic consistency on their growth, longitudinal cross-linguistic studies are needed. The present study thus contrasted concurrent growth of word and pseudoword reading efficiency, among three language/orthography groups, British-English, Czech and Slovak, over a twelve month period, from the end of first grade to the end of second grade. The linguistic and orthographic features of the two Slavic languages have been described in our earlier work (Caravolas et al., 2012); estimates of average letter-sound consistency in child-directed printed words are approximately .92 for both languages (Kessler & Caravolas, 2011), while it is .72 for English. However, the Slovak orthography was codified and reformed later than Czech, resulting in its slightly greater system-wide phonographemic consistency (Caravolas, in press).

The phase from end-Grade1 to end-Grade 2 was of particular interest because this is when learners of many alphabetic orthographies, including English, are expected to reach a watershed in reading development beyond which most become accurate, fluent, and independent readers of words in their language (e.g., Caravolas et al. 2013; Rahbari & Sénéchal, 2010; Standards & Testing Agency, 2015; Wimmer & Aro, 2003). Our previous study of the growth of *silent* word reading, which followed progress among English, Czech, and Spanish children over six time points from Reception/Kindergarten to the end of Grade 2

(Caravolas et al., 2013), showed that, despite similar levels of ability at the start of the study, the English group had faster early skill growth due to their head start in reading instruction in Reception Year (details in Participant section). However, once the consistent-orthography readers had begun formal schooling, their rate of growth increased, overtaking the English group by the end of Grade 1 and remaining ahead until the end of second grade. Based on these findings, and on the general assumptions about the facilitating effect of orthographic consistency on reading growth, a similar pattern was expected in the present study such that, by the end of first grade and over the course of second grade, Czech and Slovak children should have attained higher levels of reading-aloud proficiency and a faster rate of growth on words as well as pseudowords than English children. Regarding the development of the lexicality effect, an increase in its magnitude was expected over time for all groups, and the decoding stagnation hypothesis in English was investigated.

Method

Participants

A total of 462 children (165 English – 48% girls; 124 Czech – 52% girls; 173 Slovak – 48% girls) took part in the present study. They were participants on a broader, longitudinal study comparing literacy development in five languages from Kindergarten/Reception Year to the end of Grade 2. Children who were deemed to be readers on the basis of extreme outlier scores on the Word Reading Efficiency test at first assessment in mid-Kindergarten/Reception year (that is, 15-16 months prior to the start of the present study) were deleted from the original data set; this represented 0.005% of the sample in English, 0.01% in Czech, and 0.06% in Slovak. English participants were recruited from primary schools in the North of England; the Czech pupils came from basic schools across Bohemia, and the Slovak pupils from basic schools in the Bratislava region. Details of the broader samples along with demographic and educational information are reported in Caravolas et al. (2012, 2013). The present samples comprised those children who contributed reading scores to at least two of the three time points of this study, that is end-Grade 1 (May/June), mid-Grade 2 (November/December), and end-Grade 2 (May/June).

Participant details for age and general ability are provided in Table 1. The English group was on average one year younger than their Czech and Slovak peers, due to national differences in the age of school entry, but had started to receive formal literacy instruction in Reception Year, one year ahead of the other groups (who were at that point in Kindergarten). However, previous research (Caravolas et al., 2012, 2013), with these same groups, confirmed that they were well matched from the onset in Kindergarten/Reception Year (England) on basic cognitive abilities as well as on the precursors of literacy. Children were all monolingual speakers of the language of their country, and all had received phonically-based instruction (see Caravolas et al., 2012 for further details).

-- Insert Table 1 about here --

Measures

Parallel measures of all tests were created (unless already existing) across the three languages (see details below). The reading tests were administered individually as part of a larger assessment battery, and in the same order at each time point.

Background measures

General ability. At the start of the broader study, when all participants were in mid-Kindergarten/mid-Reception Year, the *Vocabulary* and *Block Design* subtests of the Wechsler Preschool and Primary Scale of Intelligence for Children, WPPSI-III (Wechsler, 2003) were administered. For Czech and Slovak, the English versions were adapted and standardized based on extended kindergarten-aged samples.

Reading measures

Attributes of Test items across Languages. Time-limited, one-minute, reading aloud efficiency measures comprising lists of word and pseudoword items were administered at each time point. The tests were designed to be long enough to ensure that growth in each skill could be tracked over time without the risk of reaching ceiling effects, and allowing the detection of individual variation within groups. Such measures are not designed to investigate the processes underlying children's word recognition or decoding, however, they are appropriate for studies of skill growth in young children.

Both tests were designed to be comparable across languages in terms of the constructs being measured (i.e., efficiency in reading familiar words versus efficiency in decoding novel letter strings) and in the structure, length, and key characteristics of the stimuli, while also reflecting age-appropriate printed words/letter sequences in each group's language. Summary statistics of the stimulus attributes for words and pseudowords in each language are presented in Table A1 of the Appendix. A series of ANOVAs confirmed that, (1) in line with the greater prevalence of monosyllabic words in English, the English stimuli contained on average fewer syllables than the Czech and Slovak stimuli, which did not differ from each other (words: $F(2, 418) = 14.65$, $p < .001$, $\eta^2 = .90$; pseudowords: $F(2, 418) = 11.35$, $p < .001$, $\eta^2 = .90$); in real terms, the differences were small, on average of 0.3 syllable; (2) importantly, in view of assumptions about the dominance of letter-by-letter reading among young readers, especially of consistent orthographies (e.g., Share, 2008; Ziegler & Goswami, 2005), the tests did not differ across languages on the average number of letters per item (words: $F(2, 418) =0.181$, $p > .8$; pseudowords: $F(2, 418) = 0.28$, $p > .7$); (3) English stimuli were on average somewhat more frequent than the Czech and Slovak items (see means in Table A1), which did not differ from each other ($F(2, 418) = 1459.33$, $p < .001$, $\eta^2 = .99$). In sum, the test item attributes were comparable, and where small differences occurred, they favored the English readers.

Word Reading-aloud Efficiency Test. In each language, 140 (144 in English) words were selected from corpora of children's school reading materials (Kessler &

Caravolas, 2011; Zeno, Ivens, Millard, & Duvvuri, 1995). They were of relatively high frequency (see table A1), and occurred in the grade 1 and 2 corpora of each language; thus, they were deemed to be familiar to 5-to-7-year-old children. Each list began with words consisting of single letters (e.g., *a, I,* in English), progressing to more complex monosyllables and then to two- and three-syllable words.

During individual administration, children read aloud as quickly as possible for 60 seconds from the word list, which was printed in Arial 16 pt. bold font and arranged in three columns on both sides of an A4 sheet. The number of words read correctly (including self-corrections) was recorded, while incorrectly or non-fluently read (that is, syllable- or letter-sized units were pronounced but not blended) and skipped items received a score of 0. This measure was first administered when the children were in Reception/Kindergarten, and was found to have excellent test-retest correlations in all languages (r = .98, for English; r = .88, r = .97 for Czech and Slovak, all ps < .01). Table 1 reports the test-retest reliabilites at adjacent time points covered in the present study, which are again excellent.

Pseudoword Reading-aloud Efficiency Test. The pseudoword test, constructed in the same way as the word test, was first administered at Time 1 of the present study. Its items were derived from the word items by exchange of at least the word-initial letter, and additional letters where appropriate. Crucially, the syllable structure and number of letters remained the same across word-pseudoword pairs; occasional variations arose when digraphs replaced single letter graphemes and vice versa (e.g., ‚**ch**ild‘ → ‚**j**ild‘). The number of pseudowords read plausibly in 60 seconds, including self-corrections, was recorded. In English, any possible pronunciation of the graphemes, regardless of context was considered correct; for example, for the pseudoword ‘jild’ both the pronunciations [ʤaild], [ʤɪld] were accepted. Such variations were not relevant in the Czech and Slovak versions. Implausibly or non-fluently read or skipped items received a score of 0. The reliabilities, estimated from correlations of scores obtained at adjacent time points (Time 1 with Time 2, Time 2 with Time 3), are reported for each language in Table 1; all were excellent.

Results

The descriptive statistics and reliabilities for the background variables and reading measures across all time points and language groups are reported in Table 1. The mean scaled scores on WPPSI Vocabulary and Block Design confirm that all three groups were of average ability. The reading efficiency measures were designed to assess fluency more so than accuracy. Accordingly, the error rates were low and decreased over time, as detailed in Table A2. Although the English group committed on average more errors than their Czech and Slovak counterparts, the low overall rates precluded further comparative error analyses.

Correlations between all observed reading variables across time points were very high in all languages, with similar ranges as follows: English r = .75 - .93; Czech r = .78 - .91 and Slovak r = .72 - .90. All ensuing growth curve analyses were carried out with Mplus 5.2 (Muthèn & Muthèn, 1998-2011) using Maximum Likelihood estimation. Missing values were handled with Full Information Maximum Likelihood estimation. Both tests produced roughly normal distributions across time points and language groups. Growth in word and pseudoword reading-aloud efficiency was examined in two sets of unconditional latent growth models, one focusing on between-language comparisons, the second on within-language comparisons. The sample sizes were relatively small, especially for Czech, and consequently, sample fluctuations in the residuals were anticipated. Across all models, Heywood cases (negative, nonsignificant residual variances) were fixed to zero, or to be equal over time points. Mean differences between growth constructs (intercepts, slopes) were tested using the Wald test, where appropriate. Differences involving non-linear estimated slopes were explored on the basis of the estimated factor loadings, and Cohen's d effect sizes.

Patterns of Growth in Reading-aloud Efficiency across Orthographies

To compare reading skills across groups, a three-group unconditional latent growth model of word reading efficiency, and another of pseudoword reading efficiency were constructed, each tracking growth over the three time points, at roughly six-monthly intervals.

Word Reading Efficiency. The three-group model with an initial reading status factor (intercept) at Time 1 and a linear growth factor (slope) was estimated with residuals at Time 1 and Time 3 fixed to be zero across groups. The time scores, in year units, were fixed at 0 (Time 1), .5 (Time 2) and 1 (Time 3) for the Czech and Slovak groups, while for the English group, the Time 2 score was estimated ($\lambda = 0.40$, $p < .001$), reflecting nonlinear growth. This model fitted the data very well, χ^2 (8, $N = 462$) = 15.743, $p = .05$, Comparative Fit Index (CFI) =.994, Tucker-Lewis Index (TLI) =.994, Root Mean Square Error of Approximation (RMSEA) = .079 (90% CI = .001-.137), Standardized Root Mean Residual (SRMR) =.055, and was accepted as the baseline model to test mean between-group differences in the intercept and slope. The Wald test of mean differences in intercept was not significant (W_{462} (2) =2.74, $p = .25$), indicating that English, Czech and Slovak children showed comparable levels of word reading aloud efficiency at the end of first grade. The mean difference in slope between the Czech and Slovak children was significant (W_{297} (1) =3.973, $p = .046$) indicating slightly faster growth for the Slovak group. The estimated slope for the English sample could not be similarly tested, however, the estimated factor loading ($\lambda = 0.40$, $p < .001$) indicated a slower rate of growth by Time 2 than the other two groups. Thus, while the Czech and Slovak children were acquiring word reading skills at a steady rate, having accomplished 50% of their total year's growth by mid-Grade 2, the English children had a slower start, attaining only 40% of their year's growth by Time 2, but then accelerated in the second half of the year. Moreover, the English group showed smaller reading efficiency gains between adjacent time points (Times 1 and 2: Cohen's *d* = 0.33; Times 2 and 3: *d* = 0.55) than did the Czech and Slovak groups (*d*s ranging 0.65 – 1.00). The final model, in which the intercepts were fixed to be equal over groups, provided a good fit to the data, χ^2 (10, *N* = 462) = 18.47, *p* = .05, CFI =.994, TLI =.994, RMSEA = .074 (90% CI = .008-.126), SRMR = .08. The estimated growth curves of this final model (Figure 1a), and the corresponding means of the estimated growth factors (top panel of Table 2) illustrate that, despite similar levels of word reading efficiency at the end of first grade, the rate of growth over the ensuing year varied between groups, with the English group showing slower growth than the Czech and Slovak groups, who, in turn, differed albeit negligibly.

-- Insert Table 2 --

Pseudoword Reading Efficiency. A similar model was estimated for pseudoword reading efficiency. The residual variances were fixed to be equal within groups over time due to Heywood cases. The time scores were fixed to 0 (Time 1), .5 (Time 2) and 1 (Time 3) for the English and Czech groups, while for Slovak the Time 2 score was estimated (λ = 0.61, *p* < .001), reflecting nonlinear growth. This model provided a very good fit to the data, χ^2 (8, *N* = 462) = 15.54, *p* = .05, CFI =.993, TLI =.992, RMSEA = .078 (90% CI = .004-.136), SRMR =.042, and was accepted as the baseline model to test mean between-group differences. The Wald tests indicated large differences between intercepts for English and Czech (W_{289} (1) =109.61, *p* < .001), English and Slovak (W_{338} (1) =91.50, *p* < .001), and a small, but significant difference between the Czech and Slovak (W_{297} (1) =6.37, *p* < .05) groups. However, despite the slightly lower starting level of the Slovak than the Czech group, both appeared to have attained similar levels by the end of Grade 2. To test whether the latter difference was significant, the model was respecified such that the intercept (0) was moved to Time 3, while Times 1 and 2 were fixed to -1 and -.5, respectively. The Wald test showed, as expected, that the Czech and Slovak groups did not differ in their end-Grade 2 attainments

(W_{297} (1) =0.35, p = .55). The test of slopes between the English and Czech groups revealed a small but significant difference (W_{289} (1) =4.98, p < .05), indicating a slower rate of growth in English. In contrast, the factor loading for the estimated slope for Slovak (λ = 0.61, p < .001), indicated relatively faster growth between Times 1 and 2 than the other two groups (λ = 0.50); and faster growth was corroborated by larger effect sizes in pseudoword reading gains at adjacent time points (Times 1 and 2: d = 1.10; Times 2 and 3: d = 0.61) relative to the English and Czech groups, whose effect sizes were generally smaller (d = 0.40 to d = 0.71). The final model, where the non-significant differences in intercept at Time 3 (Czech, Slovak) were fixed to be equal provided a very good fit to the data, χ^2 (9, N = 462) = 15.89, p = .07, CFI =.994, TLI =.994, RMSEA = .070 (90% CI = .000-.126), SRMR =.044. Figure 1b and the corresponding growth factor means (bottom panel of Table 2) show that, the English group underwent a slower rate of growth, and unlike for word reading, had lower attainments throughout the study relative to the consistent orthography groups, who reached similar decoding efficiency levels by the end of Grade 2.

--Insert Figure 1a and 1b --

Growth in Word Relative to Pseudoword Reading-aloud Efficiency within Orthographies

The multigroup analyses revealed indirectly that all groups had lower levels of attainment in pseudoword (Figure 1b) than in word reading (Figure 1a). The next set of within-group models compared the relative growth of these skills as well as the size of the lexicality effect as a function of time and orthographic consistency. A two-process latent growth model was constructed for each language, through a model fitting process similar to the multigroup analyses as regards fitting the intercepts, slopes, and the residuals (e.g., Heywood cases); in addition, the residual covariances were estimated between the parallel observed variables (e.g., Time 1 word reading with Time 1pseudoword reading). The lexicality effects were calculated using Cohen's d on the estimated performance means and standard deviations at each time point. Due to space constraints, these models are represented in Figures 2a, 2b, 2c, along with the final model fit indexes, and lexicality effects (full details are available from the author).

--Insert Figures 2a, 2b, 2c, about here--

As the graphs and captions in Figure 2 show, the two process models produced adequate to good fits for the data; however, none accommodated equality constraints because intercepts and rates of growth were significantly different between tasks in every language. The lexicality effect at Time 1 was largest for the English group; however, it was very large also in Slovak and Czech ($d \geq .90$), and what is more, the effect increased in magnitude over time in all languages. This was in all cases due to slower growth in pseudoword than in word reading efficiency (see also the growth construct (G) means reported in Table 2).

Discussion

The effects of system-wide orthographic consistency on the developmentally critical skills of word and pseudoword reading were considered among typically developing learners of the relatively inconsistent English orthography with learners of the relatively consistent Czech and Slovak orthographies. Each group's ability levels, respective rates of skill growth, and the magnitudes of the lexicality effect were assessed using similarly constructed and highly reliable measures, three times from the end of Grade 1 to the end of Grade 2.

On the basis of cross-linguistic, cross-sectional studies reporting on *word* reading aloud (e.g., Seymour et al., 2003; Wimmer & Aro, 2003), as well as our own longitudinal findings for silent word reading efficiency (Caravolas et al., 2013), English children were expected to achieve a poorer reading level compared to their Czech and Slovak peers by the end of Grade 1 (the start of this investigation). However, the latent growth model revealed that at end-Grade 1, all groups read words aloud with similar levels of efficiency, at a rate of just over 47 words per minute, regardless of orthographic consistency. The relatively good word reading skill of the English group is not likely to reflect specific educational effects, such as being trained on tests of speeded list reading in order to attain recently introduced early-reading benchmarks; such policies were not in place during the running of this study. The English group's result does contrast with our earlier finding of a clear lag in silent word reading at end-Grade 1 (Caravolas et al., 2013), and suggests that orthographic consistency effects manifest earlier in silent reading than in reading aloud. This in turn raises important questions about the extent to which one can generalize about development across these two reading modes (cf. Share, 2008).

These considerations aside, parity of the groups on word reading efficiency at the start of this study provided an excellent baseline for further examinations of word as well as pseudoword reading growth. Indeed by mid-Grade 2, the English children were on a slower word-reading trajectory than their Czech and Slovak counterparts; and despite the English group's relative acceleration of growth in the second half of Grade 2, the gap between them and the other groups continued to increase. Yet, it is important to note that in actual performance terms, the difference in reading efficiency at end-Grade 2 was relatively small, with the English group reading approximately seven words-per-minute fewer than their Slavic peers. The Czech group showed somewhat slower growth than their Slovak counterparts, but again, the words-per-minute difference was marginal. Whether the small lag of the Czech group reflected random sampling differences, given their relatively small sample size, or more interestingly, whether it reflected the impeding effects of the subtly lower system-wide consistency of the Czech orthography (Caravolas, in press) is not clear, and this issue awaits further research. However, if the latter were true, this would suggest that even subtle differences in consistency can manifest in measurable differences in the early word reading growth of different language/orthography groups.

The present paper (to our knowledge) reports the first longitudinal investigation of the influence of orthographic consistency on the latent growth pattern of *pseudoword* reading. Thus, expectations about the growth trajectories for this skill were guided by previous cross-sectional studies, which consistently indicated poorer pseudoword decoding skills for readers of English than those of more consistent orthographies (e.g., Landerl et al., 1997; Patel et al., 2004; Seymour et al., 2003; Wimmer & Aro, 2003). Accordingly, at a point in reading development when all three groups were reading *words* with similar levels of efficiency, the English children were reading approximately 15 fewer pseudowords per minute than Czech and Slovak readers, and this gap increased to approximately 18 items per minute at the end of Grade 2 (see bottom panel of Table 2). The Slovak group had a marginally lower initial level of performance than the Czech group, but had caught up by the end of Grade 2, again indicating a slightly faster growth rate.

The within-language models were carried out primarily to assess the *lexicality effect:* its magnitude and developmental changes, as a function of orthographic consistency. As demonstrated in Figures 2a – 2c, and in line with theoretical predictions (Van den Broeck & Geudens, 2010) and indications from cross-linguistic, cross-sectional studies (e.g., Patel et al., 2004; Wimmer & Aro, 2003), smaller lexicality effects were obtained in Slovak and Czech than in English, but, the effect increased over time in all groups. The analyses thus did not provide evidence of Van den Broeck and Geudens' (2012) specific hypothesis that *typical* readers of less consistent orthographies, in this case English, might undergo a process of decoding stagnation (i.e., a deceleration of pseudoword reading growth), due to their decreasing reliance on decoding strategies during word reading. The small indication of deceleration in Slovak, the group with arguably the highest relative orthographic consistency, was more likely indicative of a transient plateauing of skill growth than of deceleration. The latter findings must remain tentative, however, because within this three-measurement-points design, it was difficult to robustly test the strength of the components of the non-linear trajectory. In addition, it is possible that the developmental phase under study predated long-term growth changes in any of the languages. We return to these issues below.

The results of the present study indicate that the costs of orthographic *in*consistency on alphabetic reading development are greater for the acquisition of decoding skills than for the growth of real word reading, as evidenced by the relatively low scores of English children on the pseudoword task. However, when considered within the theoretical framework of the self-teaching hypothesis, the cloud of orthographic inconsistency of English may, after all, have a silver lining. That is, to the extent that pseudoword reading is *the* proxy measure for the foundational skill that drives orthographic learning and efficient word reading (Share, 1995), the present results may indicate that English readers are better able to capitalize on their less developed decoding skills to access and acquire orthographic representations of real words than their consistent-orthography-learning counterparts. Despite their considerable lag in pseudoword reading at the end of first grade, the English children had levels of word reading efficiency equivalent to their Czech and Slovak peers; thereafter, their word reading lag remained relatively small.

The processes that gave rise to these language-specific growth patterns were not investigated in the present study, nor was the quality of the orthographic representations underpinning children's word reading performance. Nevertheless the results invite some interesting interpretations. For instance, the greater word reading advantage of the English group may reflect their tendency to use more flexible (large and small grain) grapho-phonological mapping strategies when reading words than when reading pseudowords, as may be inferred from the psycholinguistic grain size theory (Ziegler & Goswami, 2005). While possible, task-specific differences in grapho-phonemic mapping strategies are unlikely to account fully for the present results in the light of accruing evidence that, already in the early stages of learning to read, English children's imperfect decoding skills are supplemented by their extant lexico-semantic knowledge (Duff & Hulme, 2012; Laing & Hulme, 1999; Nation & Cocksey, 2009). Thus relatively good word reading aloud performance may be achieved by partial grapho-phonemic decoding in combination with lexical knowledge, and, may be underpinned by more or less well specified orthographic representations (see also Ehri, 2005, 2015; Landerl et al. 1997).

It is equally important to note that very large lexicality effects were consistently obtained in the Czech and Slovak groups, clearly showing that learners of consistent orthographies also draw large benefits from real word reading experience. The word reading advantage in consistent orthographies presumably reflects some form of lexicalization (e.g., Rahbari & Sénéchal, 2010). Interesting recent evidence from German studies suggests that this effect may in fact reflect children's ever more efficient serial decoding strategies (as opposed to whole word recognition) at least to fourth grade (e.g., Gagl, Hawelka & Wimmer, 2015; Rau, Moeller, & Landerl, 2014). Moreover, it is equally plausible, in line with a language-general connectionist *division of labour* account of reading (e.g., Seidenberg, 2011), that, over and above the benefits of grapho-phonemic consistency, the word reading advantage in consistent orthographies reflects dynamic contributions of lexico-semantic knowledge to children's more or less well established orthographic representations, as occurs in English, although this contribution may be less important for successful word recognition (e.g., Goswami, Ziegler, Dalton, & Schneider, 2001). The validity of this hypothesis, and the relative contribution of each type of knowledge to word reading over the course of development in different alphabetic orthographies remains to be investigated in future longitudinal cross-linguistic studies.

Finally, the very high correlations observed in the present study between word and pseudoword reading skills across languages and time points, despite clear between-language differences in skill levels and growth rates, is consistent with the view that a tight functional relationship between decoding skills and word reading skills comprises the self-teaching mechanism in alphabetic reading development (Share, 1995).

The present study set the stage for further cross-linguistic investigations of early reading growth. As noted earlier, growth curve modelling of three time points has limitations in that non-linear growth patterns cannot be easily interpreted in such models. Also, while the three time points examined here captured development in the run up to the putative change in emphasis from ‘learning-to-read’ to ‘reading-to-learn’, it precluded the tracking of more skilled reading development, that could moreover shed light on the decoding stagnation hypothesis, and the predictive interrelationships between word and pseudoword reading skills over a longer time span. Issues such as these should be investigated in future direct cross-linguistic studies that span a longer learning period and sample a wider range of the orthographic consistency spectrum.

References

Adelman, J., Sabatos-DeVito, M., Marquis, S., J., & Estes, Z. (2014). Individual differences in reading aloud: A mega-study, item effects, and some models. *Cognitive Psychology*, *68*, 113-160. DOI:10.1016/j.cogpsych.2013.11.001

Caravolas, M. (in press). Learning to read in Czech and Slovak. In L. Verhoeven & C. E. Perfetti (Eds.), *Learning to read across languages and writing systems.* Cambridge, UK: Cambridge University Press.

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

Caravolas, M., Lervåg, A., Mousikou, P., Efrim, C., Litavský, M., Onochie-Quintanilla, E., … Hulme, C. (2012). Common patterns of prediction of literacy development in different alphabetic orthographies. *Psychological Science*, *23*, 678-686. DOI: 10.1177/0956797611434536.

Caravolas, M., & Samara, A. (2015). Learning to read and spell words in different writing systems. In A. Pollatsek & R. Treiman (Eds.), *The Oxford handbook of reading* (pp. 326-343) New York, NY: Oxford University Press.

Cunningham, A. E., Perry, K. E., Stanovich, K. E., & Share, D. L. (2002). Orthographic learning during reading: Examining the role of self-teaching. *Journal of Experimental Child Psychology, 82*, 185–199.

De Jong, P. F., & Messbauer, V. C. (2011). Orthographic context and the acquisition of orthographic knowledge in normal and dyslexic readers. *Dyslexia*, *17*, 107-122. DOI: 10.1002/dys.427

Ehri, L. (2005). Development of sight word reading: Phases and findings. In M. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 135-154). Oxford, England: Blackwell.

Ehri, L. (2015). How children learn to read words. In A. Pollatsek & R. Treiman (Eds.), *The Oxford Handbook of Reading* (pp. 293-310). New York, NY: Oxford University Press.

Goswami, U., Ziegler, J. C., Dalton, L., & Schneider, W. (2001). Pseudohomophone effects and phonological recoding procedures in reading development in English and German. *Journal of Memory and Language*, *45*, 648–664.

Herrmann, J. A., Matyas, T., & Pratt, C. (2006). Meta-analysis of the nonword-reading deficit in specific reading disorder. *Dyslexia*, *12*, 195–221. http://dx.doi.org/10.1002/dys.324

Kessler, B., & Caravolas, M. (2011). Weslalex: *West Slavic lexicon of child-directed printed words*. Retrieved from http://spell.psychology.wustl.edu/weslalex

Kessler, B., & Treiman, R. (2015). Writing systems: Their properties and implications for reading. In A. Pollatsek & R. Treiman (Eds.), *The Oxford Handbook of Reading* (pp. 10–25). New York, NY: Oxford University Press.

Landerl, K., Wimmer, H., & Frith, U. (1997). The impact of orthographic consistency on dyslexia: A German-English comparison. *Cognition*, *63*, 315-334. DOI: 10.1016/S0010-0277(97)00005-X.

Muthèn, L. K., & Muthèn, B. O. (2010). *Mplus user's guide* (5th ed.). Los Angeles, CA: Author.

Patel, T. K., Snowling, M. J., & De Jong, P. F. (2004). Learning to read in Dutch and English: A cross-linguistic comparison. *Journal of Educational Psychology*, 96, 785–797. http://dx.doi.org/10.1037/0022-0663.96.4.785.

Perfetti, C. A. (2007). Reading ability: Lexical quality to comprehension. *Scientific Studies of Reading,11*, 357-383.

Perfetti, C. A. (2010). Decoding, vocabulary, and comprehension: The golden triangle of reading skill. In M. G. McKeown & L. Kucan (Eds.), *Bringing reading research to life: Essays in honor of Isabel Beck* (pp. 291-303). New York: Guilford.

Perfetti, C.A., & Hart, L. (2002). The lexical quality hypothesis. In L. Verhoeven. C. Elbro, & P. Reitsma (Eds.), *Precursors of functional literacy* (pp. 189-213). Amsterdam/Philadelphia: John Benjamins.

Rahbari, N., & Sénéchal, M. (2010). Learning to read and spell in Persian: A cross-sectional study from grades 1 to 4. *Developmental Psychology, 46,* 1514-1527. DOI: 10.1037/a0020377

Rack, J. P., Snowling, M. J., & Olson, R. K. (1992). The nonword-reading deficit in developmental dyslexia: A review. *Reading Research Quarterly*, *27*, 29–53. http://dx.doi.org/10.2307/747832.

Rayner, K., & Reichle, E. D. (2010). Models of the reading process. *Wiley Interdisciplinary Reviews: Cognitive Science*, *1*, 787–799. doi:10.1002/wcs.68.

Seidenberg, M. S. (2011). Reading in Different Writing Systems: One Architecture, Multiple Solutions In P. McCardle., J. Ren., & O. Tzeng. (Eds.), *Across languages: Orthography and the Gene-Brain-Behavior Link*. Paul Brooke Publishing.

Seymour, P. H. K., Aro, M., & Erskine, J. M. (2003). Foundation literacy acquisition in European orthographies. *British Journal of Psychology, 94*, 143–174. http://dx.doi.org/10.1348/000712603321661859.

Share, D. L. (1995). Phonological recoding and self-teaching: *Sine qua non* of reading acquisition. *Cognition, 55,* 151–218. http://dx.doi.org/10.1016/0010-0277(94)00645-2.

Share, D. L. (2004). Orthographic learning at a glance: On the time course and developmental onset of self-teaching. *Journal of Experimental Child Psychology*, *87*, 267–298. http://dx.doi.org/10.1016/j.jecp. 2004.01.001.

Share, D. L. (2008). On the Anglocentrism of current reading research and practice: The perils of overreliance on an "outlier orthography. *Psychological Bulletin, 134*, 584–615. DOI: 10.1037/0033-2909.134.4.584

Sprenger-Charolles, L., Colé, P., & Serniclaes, W. (2006). *Reading Acquisition and Developmental Dyslexia*. Hove, UK: Psychology Press.

Standards &Testing Agency (2015). *Interim teacher assessment framework at the end of key stage 1*. retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/461547/Interim_teacher_assessment_frameworks_at_the_end_of_key_stage_1_PDFA.pdf.

Van den Broeck, W. & Geudens, A. (2012). Old and new ways to study characteristics of reading disability: The case of the nonword-reading deficit. *Cognitive Psychology*, *65*, 414-456. http://dx.doi.org/10.1016/j.cogpsych.2012.06.003

Van den Broeck, W., Geudens, A., & van den Bos, K. P. (2010). The nonword reading deficit of disabled readers: A developmental interpretation. *Developmental Psychology, 46*, 717–734. http://dx.doi.org/10.1037/a0019038.

Wechsler, D. (2003). *Wechsler Preschool and Primary Scale of Intelligence—Third UK Edition (WPPSI-III*UK*)*. Oxford, England: Psychological Corp.

Wimmer, H., & Aro, M. (2003). Learning to read: English in comparison to six more regular orthographies. *Applied Psycholinguistics, 24*, 621-635.

Zeno, S.M., Ivenz, S.H., Millard, R.T., & Duvvuri, R. (1995). *Educator's word frequency guide*. Brewster, NY: Touchstone Applied Science Associates.

Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. Psychological Bulletin, 131(1), 3–29. http://dx.doi.org/10.1037/0033-2909.131.1.3.

Table 1

Participant Details and Means, Standard Deviations and Reliabilities for all Variables at all Time Points for all Groups

	English		Czech		Slovak	
	M (sd)	Reliability	*M (sd)*	Reliability	*M (sd)*	Reliability
Age (months) at T1	75.01 (3.69)	--	87.28 (3.86)	--	86.80 (3.71)	--
WPPSI Vocabulary (Scaled score)	9.64 (2.64)		10.15 (3.14)	--	9.99 (2.95)	--
WPPSI Block Design (Scaled score)	10.21 (3.10)		10.38 (2.72)	--	10.28 (2.99)	--
Word Reading Efficiency Time 1	49.06 (26.31)	.93[1]	48.91 (16.13)	.83[1]	46.24 (14.85)	.86[1]
Word Reading Efficiency Time 2	57.23 (26.51)	.91[2]	65.07 (18.66)	.87[2]	62.21 (17.45)	.90[2]
Word Reading Efficiency Time 3	71.09 (23.56)	---	77.86 (19.28)	--	77.91 (18.02)	--
Pseudoword Reading Efficiency Time 1	21.13 (14.18)	.84[3]	36.55 (11.51)	.83[3]	33.86 (9.57)	.78[3]
Pseudoword Reading Efficiency Time 2	27.96 (16.08)	.87[4]	46.12 (12.63)	.82[4]	45.09 (10.75)	.88[4]
Pseudoword Reading Efficiency Time 3	34.62 (16.74)	--	52.61 (14.37)	--	52.20 (12.67)	--

Note. [1] = correlations between 1 Minute Reading at first and second time point; [2] = correlations between 1 Minute Reading at second and third time point; [3] = correlations between 1 Minute Pseudoword Reading at first and second time point ; [4] = correlations between 1 Minute Pseudoword Reading at second and third time point.

Table 2

Means, Standard Deviations of the Unconditioned Multigroup Growth Models for Word and Pseudoword Reading Aloud Efficiency.

Growth Constructs	Word Reading Efficiency by Language			
	English	Czech	Slovak	Differences in means
Mean (SD)				
Initial Status (I)	**47.52** ** (26.51**)	**47.52** ** (16.19**)	**47.52** ** (14.91**)	Eng = Cz = Sk
Growth (G)	22.41** (14.02**)	28.98** (10.09**)	31.57** (11.63**)	Eng < Cz < Sk
	Pseudoword Reading Efficiency by Language			
Mean (SD)				
Initial Status (I)	21.16** (13.35**)	37.04** (10.33**)	33.87** (8.72**)	Eng < Cz, Sk, Cz > Sk
Final Status (F)	34.63**(16.21**)	**52.56**** (13.18**)	**52.56****(11.99**)	Eng < Cz = Sk
Growth (G)	13.48** (6.91**)	15.88** (4.83)	18.51** (7.02**)	Eng < Cz < Sk

Note. Means in bold did not differ over groups and were hence fixed to be equal over groups. Variance in mean constructs and their standard deviations: $*p < .05$; $**p < .01$.

Appendix 1

Table A1

Stimulus Attributes of Word and Pseudoword Reading Efficiency Tests as a Function of Language Group.

	Language			
	English (n^a = 144)	Czech (n^a = 140)	Slovak (n^a= 140)	
Words	Mean (SD)	Mean (SD)	Mean (SD)	Group Differences
Mean Syllables/Item	1.33 (0.50)	1.63 (0.51)	1.61 (0.52)	Eng < Cz = Sk
Mean Letters/Item	4.31 (1.61)	4.30 (1.30)	4.21 (1.32)	*ns*
Mean Frequency - SFI[b]	69.65 (6.42)	63.81 (7.89)	64.43 (7.68)	Eng> Cz = Sk
Pseudowords				
Mean Syllables/Item	1.35 (0.53)	1.61 (0.49)	1.61 (0.52)	Eng < Cz = Sk
Mean Letters/Item	4.32 (1.60)	4.23 (1.26)	4.20 (1.32)	*ns*

Note: [a]: *n* refers to the number of items in the test for each language. [b]: SFI = Standardized Frequency Index derived from Zeno et al, (1995) for English and from Kessler & Caravolas, (2011) for Czech and Slovak.

Appendix 2

Error Analyses

The error data on the Word and Pseudoword Reading Aloud Efficiency Tests were first checked for extreme outliers, and these were trimmed to 2.5 SD above each group's mean at each time point. The percentage of extreme outliers ranged from 0.6% to 4.4% across groups for word reading, and from 0.6% to 4.1% for pseudoword reading.

Table A2.

Errors Means and Standard Deviations for Word and Pseudoword Reading Aloud Efficiency Tests as a Function of Language Group and Time.

	Word Errors			Pseudoword Errors		
	T1 M (SD)	*T2 M (SD)*	*T3 M (SD)*	*T1 M (SD)*	*T2 M (SD)*	*T3 M (SD)*
English	5.14 (4.71)	3.62 (3.63)	2.33 (2.88)	7.05 (6.12)	6.45 (5.42)	5.87 (5.74)
Czech	2.13 (2.33)	1.03 (1.58)	0.64 (1.03)	3.85 (3.43)	3.22 (3.41)	2.81 (3.18)
Slovak	2.24 (2.22)	1.33 (1.54)	0.96 (1.26)	3.27 (2.35)	3.62 (3.41)	2.67 (2.21)

All distributions significantly positively skewed ($p < .001$) after trimming.

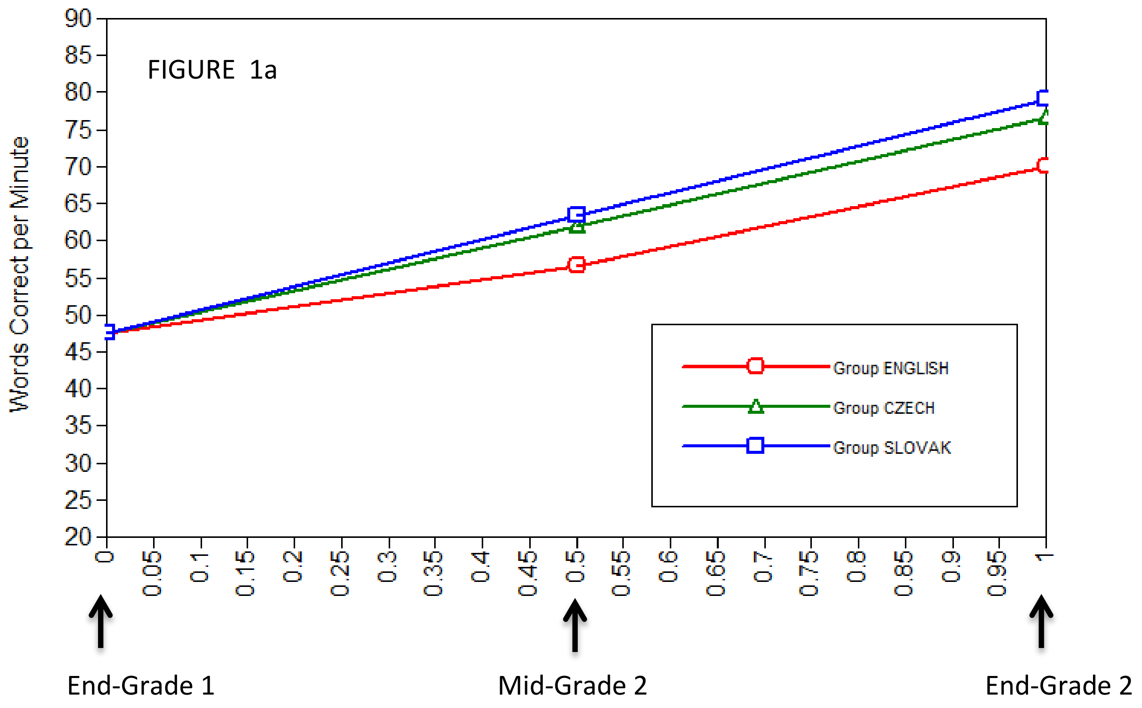


Figure 1a
Estimated Means for the Unconditional 2-Factor Growth Model of Word Reading Aloud Efficiency

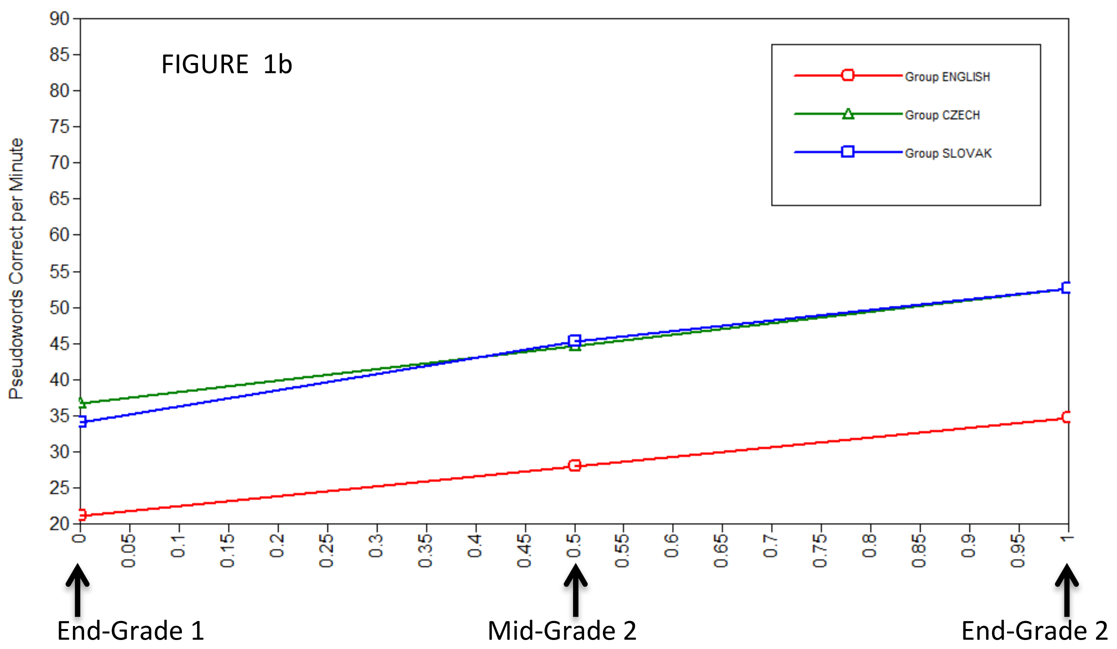
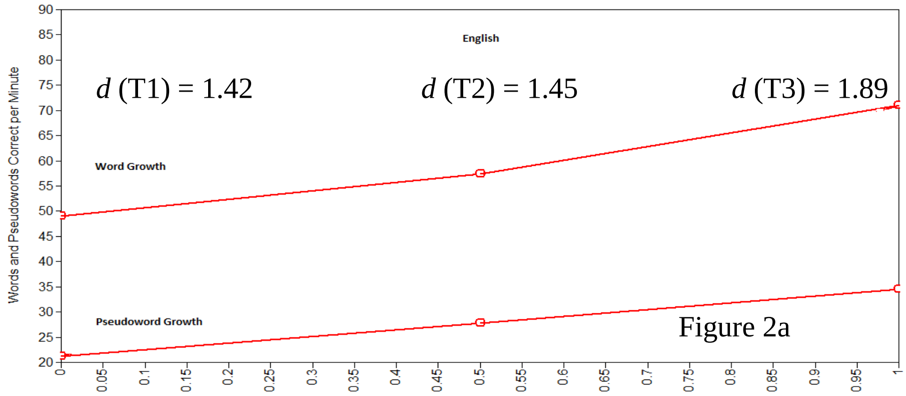
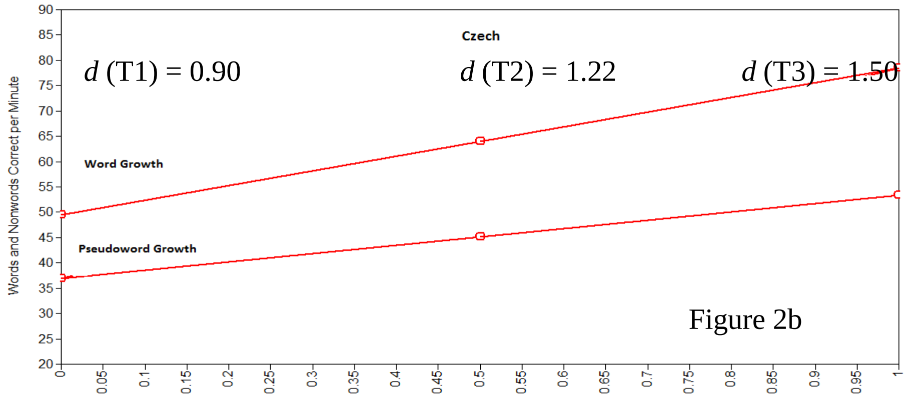


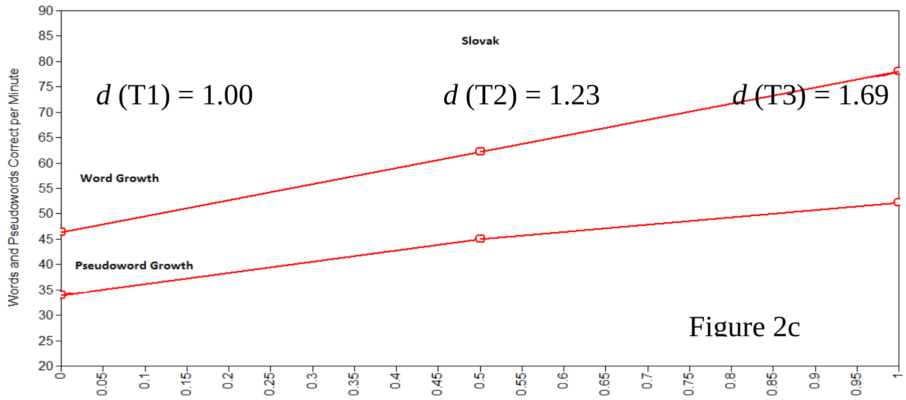
Figure 1b
Estimated Means for the Unconditional 2-Factor Growth Model of Nonword Reading Aloud Efficiency



χ^2 (5, *N* = 165) = 12.16, *p* = .03, CFI =.994, TLI =.983, RMSEA = .093 (90% CI = .025-.161), SRMR =.041.



χ^2 (5, *N* = 124) = 10.19, *p* = .07, CFI =.994, TLI =.983, RMSEA = .092 (90% CI = .000-.172), SRMR =.034.



χ^2 (7, *N* = 173) = 15.66, *p* = .03, CFI =.994, TLI =.986, RMSEA = .085 (90% CI = .026-.141), SRMR =.063.

Figure 2a, 2b, 2c

Estimated Means for the Unconditional 2-Process Growth Models of Word Reading-aloud and Nonword Reading-aloud Efficiency in English (2a), Czech (2b), and Slovak (2c), with Cohen's *d* estimates of the lexicality effect at each time point, and model fit indexes. On the *X* axis, 0 = End-Grade 1, 0.5 = Mid-Grade 2, and 1 = End-Grade 2.