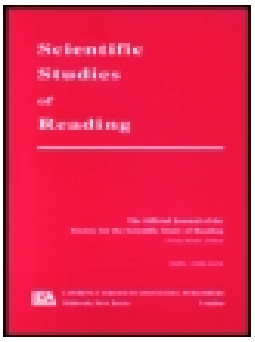

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The Effect of Syllable-level Hyphenation on Novel Word Reading in Early Finnish Readers: Evidence from Eye Movements

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ABSTRACT

In early Finnish reading instruction, hyphens are used to denote syllable boundaries. However, this practice slows down reading already during the 1st grade. It has been hypothesized that hyphenation forces readers to rely more on phonology than orthography. Since hyphenation highlights the phonology of the word, it may facilitate reading during the very first encounters of the word. To assess whether this is the case, Finnish 1st and 2nd graders read stories about fictional animals while their eye movements were registered. Each story included four occurrences of a novel target (pseudo) word, hyphenated at the syllable level in half of the stories. Target words were read faster with repeated exposure but there were no effects regarding grade or hyphenation. The use of hyphenation does not give rise to enhanced processing of phonology in novel words and is likely to hinder the processes connected to the use of orthography.

Finnish is a language with shallow orthography and simple syllable structure (Seymour, Aro, & Erskine, 2003). Early Finnish reading instruction emphasizes the syllable structure by explicitly cueing the syllable boundaries with hyphens (e.g., en-ter). In the beginning, each word with two or more syllables is hyphenated. Hyphens are then gradually removed but preserved in new and long words until the end of the 2nd grade. This is done in order to help children break down the words into more easily digested pieces. However, even though Finnish children utilize syllable information in early reading (Häikiö, Hyönä, & Bertram, 2015; Hautala, Aro, Eklund, Lerkkanen, & Lyytinen, 2012), hyphenation slows down reading already during the 1st grade (Häikiö et al., 2015). The slowdown is even larger in longer words (Häikiö, Bertram, & Hyönä, 2016). Hyphenation also disrupts integration, as the slowdown is more strongly associated with rereading the beginning of the sentence (Häikiö et al., 2016, 2015). Finally, problems in integration result in poorer reading comprehension regardless of the individual's comprehension skills for 2nd graders (Häikiö, Heikkilä, & Kaakinen, 2018). To our knowledge, there are no studies in other languages comparing reading of syllable-congruent hyphenated vs. non-hyphenated words.

Häikiö and colleagues have argued that their findings are due to hyphenation directing attention to single syllables at a time, leading to a more piecemeal, phonological access than would be preferred otherwise. According to Häikiö and colleagues, even Finnish 1st graders try to utilize orthography alongside phonology. This goes well with the finding that Finnish children learn to read relatively faster than in other European languages (Seymour et al., 2003). In fact, most Finnish children are fluent decoders by the 1st grade Christmas (Seymour et al., 2003). These findings may also be interpreted in the light of the dual-route model of orthographic processing (Grainger & Ziegler, 2011). According to this model, skilled readers access the word meaning simultaneously utilizing all possible routes, be it phonology, letter level orthography or whole word representation.

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Even though hyphenation disrupts reading of familiar Finnish words, the situation may be different for novel words. According to the self-teaching hypothesis, novel words are learned via phonological recoding (Share, 1995); since there cannot be an orthographic representation of a word one has never seen before, reader cannot rely solely on the visual form. Instead, phonological codes must be used. This is true even for the skilled readers, who usually rely more on orthography than phonology in word reading (e.g., Grainger, Lété, Bertand, Dufau, & Ziegler, 2012). Indeed, an eye movement study by Brusnighan, Morris, Folk, and Lowell (2014) demonstrates that phonology is activated in reading novel words even for skilled adult readers as witnessed in a larger interference when the novel word shared a phonological form with an existing word.

Furthermore, reliance on phonology may be more pronounced in a language with shallow orthography such as Finnish, in which the grapheme-phoneme correspondence is more straight-forward than in a language with deep orthography. This division is taken into account in the psycholinguistic grain size theory (Ziegler & Goswami, 2005) which suggests that early readers in shallow orthographies can rely on phonology for longer than readers in deep orthographies. If this is the case, an early Finnish reader might benefit from explicit cues signaling the phonological building blocks such as syllables.

In the present study, Finnish 1st and 2nd grade children read short stories of fictional animals while their eye movements were registered. In order to be sure that the participants had no prior exposure to the targets, we used pseudowords as target words. In each story, a target appeared a total of four times. For half of the stories, the targets were hyphenated while for the other half they were not. We had the following research questions:

(1) Is there a repeated reading effect for both grades (speed-up in the eye movement measures)?

(2) Is phonology more important than orthography in reading novel words (facilitating effect of hyphenation), or does orthography play a substantial role (no effect or a slowdown caused by hyphenation)?

(3) Is there a rapid change from phonology to orthography (an interaction between hyphenation and exposure)?

Method

Participants

Twenty-two monolingual 1st graders (7 females, range 7:4–8:1 years) and 25 monolingual 2nd graders (18 female, range 8:2–9:1) were recruited from a Finnish elementary school. Four 1st grade participants did not complete the eye movement task (two due to equipment malfunction, two due to very slow reading; all males). They were not included in the analyses. At the time of testing, 1st and 2nd graders had received approximately 6 months, and 1 year 6 months of formal reading instruction, respectively. All participants had normal or corrected-to-normal vision. The ethical principles of the Declaration of Helsinki were followed. The Ethics Committee for Human Sciences of the University of Turku required no ethical review as all participants were voluntary and children's legal guardians signed a written informed consent form prior to the experiment. Furthermore, the school authorities granted permission for the study. The participants received candy as a reward for participation.

Apparatus

Eye movements were recorded monocularly with the EyeLink Portable Duo (SR Research, Canada) with a sampling rate of 500 Hz. A chin-and-forehead rest installed 60 cm in front of the screen was used to minimize head movements. The texts were presented on a 17.3-inch Asus ROG G752V laptop (refresh rate of 120 Hz, resolution 1920*1080).

Materials

Eighteen pseudowords (targets from now on) were constructed following the Finnish syllabification rules. Twelve targets were bisyllabic (six with CVC.CV structure, six with CVV.CV), and six were trisyllabic (CV.CV.CV). Two bisyllabic targets were preserved for the practice session. The remaining 16 targets were divided in two lists of 5 bisyllabic and 3 trisyllabic words. The lists did not differ in terms of close or open bigram frequency, $t(14) = .24$, $d = .12$, and $t(14) = -.07$, $d = -.04$, respectively.

The targets were embedded in short stories constructed following the format used in a standardized reading comprehension test, Diagnostiset testit 2 (Vauras, Mäki, Dufva, & Hämäläinen, 1995). Each story (two practice stories and 16 experimental stories) was about a certain fictional animal species and consisted of four sentences. The targets acted as the names of the species and were inserted in each sentence. Each target appeared four times within its carrier story. The target was never the first or last word of a sentence. The target words were separated from each other on average by 7.65 words (SD = 3.21, range 3–15). The stories were approved suitable for 1st and 2nd grade children by an elementary school teacher.

The stories were presented in a proportional Calibri font with a font size 50. With a viewing distance of 60 cm, one character subtended from .30 to .99 degrees of visual angle. On the top of the screen there was a 112-pixel margin, and on the left and right side a 200-pixel margin. The stories consisted on an average of 36.50 words (SD = 4.80, range 28–42). The words were on average 6.56 characters long (SD = 2.56, range 2–15). Each story fitted on one screen with a maximum of 7 lines extending horizontally up to 61 characters in length.

The 16 experimental stories were divided into four blocks (A to D) of four stories. The block presentation order was counterbalanced between the participants, resulting in four different presentation lists (ABCD, BADC, CDAB, DCBA). For each story, a version with targets hyphenated at the syllable boundaries was constructed. The other words were never hyphenated. Four alternative blocks with hyphenated stories (A' to D') were created. The hyphenated and non-hyphenated blocks were presented in an alternating fashion (e.g., AB'CD'); each participant read two blocks of non-hyphenated and two blocks of hyphenated stories. Every second participant started with a non-hyphenated block, while every other started with a hyphenated block. After each story, the participants were asked two true/false questions to make sure they made effort to comprehend the stories.

After the eye movement experiment, technical reading skill and working memory capacity were assessed. The technical reading skill was assessed with the word fluency subtest of Lukilasse 2 (Häyrinen, Serenius-Sirve, & Korkman, 2013), in which the children had 2 minutes to read correctly as many words as possible from a list of 90 words. The average score was 59.67 (SD = 16.94, range 17–89). The working memory capacity was assessed with the Digit Span subtest of WISC-IV (Wechsler, 2003). The average raw score was 12.07 (SD = 1.75, range 8–16). As these measures did not interact with hyphenation, they are not considered further for the brevity's sake.

Procedure

The participants were instructed to read stories for comprehension at their own pace. They were encouraged to read silently. They were told that after each story they would get oral questions about the story they just read. Furthermore, they were told that some stories would contain hyphenated words, but that the other stories would not. The eye-tracker was calibrated using a nine-point calibration. Calibration was deemed successful if the average error was <0.50 degrees. However, for six participants we had to use a less stringent calibration criteria (M = 0.66 degrees, SD = 0.25, range 0.52–1.16). As the visual data inspection indicated that the accuracy was satisfactory in order to differentiate eye fixations on different words, we included these data in the analyses. Before each text screen, the participant fixated on a circle at the left side of the screen, after which the text appeared. Before the experimental stories, the participants read two practice stories and answered the questions.

After the practice, the 16 experimental stories were presented, each followed by corresponding comprehension questions.

Dependent variables and predictors

The data were analyzed on the target level. We used four standard dependent variables to assess the reading behavior; first fixation duration (FFD), gaze duration (GD; summed duration of fixations on a word before it is exited for the first time), go-past time (GPT; summed duration of fixations from the first fixation on a word until it is exited to the right for the first time), and number of first-pass fixations (NoF). The duration variables were chosen as they represent different aspects of word processing (initial impact, decoding, and integration, respectively). Furthermore, NoF supplements the GD analysis.

The item-level predictors were Syllable Boundary Cue (*SBC*) with two levels, Control and Hyphen, and the *Index* number of the target word within the story as a continuous variable. Furthermore, the quadratic term of Index was entered in the model to see whether possible effects are of linear or quadratic nature. *Grade*, a participant-level predictor with two levels (1^{st} and 2^{nd} grade) was also entered in the models.

Statistical considerations

Three 1^{st} graders read only half of the stories (eight in total) but their data were included nevertheless. Target data were excluded if (1) the pupil was missing consecutively for 200 ms, (2) the pupil was missing in total for 300 ms, (3) the target was skipped during the first reading, or (4) at least half of the words in the carrier sentence were not fixated during the first reading. This led to the exclusion of 8.6% of the data for the 1^{st} grade, and 5.0% for the 2^{nd} grade. Furthermore, all fixations after the participant reached the end of the story were excluded.

The duration measures were log-transformed to normalize the data. Durations 2.5 SDs larger than the participant mean were excluded separately for both conditions. This lead to the exclusion of 1.0% of the remaining data for FFD and GPT, and 1.3% of the remaining data for GD.

We used multiple regression mixed-effects modeling for the duration measures and its generalized variant with Poisson function for NoF with participants and items as crossed random effects. The predictor variables were initially entered in the random structure. As the models with maximal random structure failed to converge, we had to use less stringent random structures. Post hoc contrasts were calculated for the main effect of Index by comparing consecutive occurrences of the target (i.e., 1 vs 2, 2 vs 3, and 3 vs 4). The 95% confidence intervals for the contrasts were computed using Wald estimation. The linear mixed-effects analyses were conducted using the lme4 package (version lme4_1.1.21; Bates, Maechler, Bolker, & Walker, 2015) and the contrasts were calculated using the glht() function of the multcomp package (version multcomp_1.4–12; Hothorn, Bretz, & Westfall, 2008) for R statistical software (version 3.6.3; R Core Team, 2020). The models including final random structures are reported in Tables A1-A4 in the Appendix.

We also conducted a set of Bayesian analyses. For the sake of brevity, they are reported in full in the Supplementary Materials. In the following, we mention Bayes Factors (BF) when they diverge from the results of the linear mixed-effects models.

Results

The non-transformed means and standard deviations for the dependent variables are presented in Table 1. There was a reliable main effect of SBC in FFD (see Appendix Table A1); hyphenated words elicited shorter first fixations. The main effect of SBC in GPT did not get further support by BF. There was no reliable main effect of Grade in any measure. On the contrary, Index elicited sizable main effects in each measure, even though this effect was not confirmed by BF in FFD. This effect was due to each target eliciting shorter reading times or less fixations than the previous occurrence apart from the comparison of Word 2 vs Word

Table 1. Non-transformed means and standard deviations (in parentheses) for the dependent variables.

	Grade 1								Grade 2							
	Control				Hyphen				Control				Hyphen			
Variable	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
First Fixation Duration (ms)	414 (274)	405 (307)	385 (372)	352 (335)	412 (294)	308 (238)	326 (270)	278 (245)	379 (275)	360 (254)	330 (195)	310 (180)	332 (183)	309 (192)	307 (175)	296 (187)
Gaze Duration (ms)	1479 (1039)	1190 (1061)	998 (911)	900 (909)	1539 (1208)	1222 (1151)	908 (697)	917 (921)	1289 (837)	1049 (802)	954 (861)	820 (682)	1229 (830)	1103 (725)	964 (675)	948 (727)
Go-Past Time (ms)	1758 (1279)	1479 (1246)	1302 (1464)	1209 (1124)	1949 (1338)	1610 (1334)	1502 (1282)	1358 (1283)	1568 (1196)	1258 (930)	1181 (1024)	1153 (956)	1568 (917)	1294 (861)	1225 (787)	1134 (790)
Number of First-Pass Fixations	3.47 (2.19)	2.71 (1.75)	2.73 (1.80)	2.41 (1.41)	3.93 (2.69)	3.32 (2.01)	2.78 (1.74)	2.96 (2.08)	3.58 (2.28)	2.88 (1.90)	2.71 (1.89)	2.41 (1.62)	3.55 (2.20)	3.42 (2.04)	2.98 (1.79)	3.06 (1.93)

Note: W = Word.

Table 2. Post hoc contrasts (B) between word indexes. Ninety-five percent confidence intervals in brackets.

	W1 vs. W2	W2 vs. W3	W3 vs. W4
First Fixation Duration	−.129 [−.192, −.067]	−.006 [−.069, .058]	−.081 [−.145, −.017]
Gaze Duration	−.223 [−.299, −.148]	−.171 [−.247, −.094]	−.076 [−.153, .001]
Go-past Time	−.259 [−.321, −.197]	−.100 [−.162, −.037]	−.064 [−.127, −.001]
Number of First-Pass Fixations	−.172 [−.233, −.110]	−.092 [−.159, −.026]	−.032 [−.101, .037]

Note: Durations have been log-transformed.

3 in FFD and Word 3 vs Word 4 in NoF (see Table 2). There was a main effect of the quadratic term of Index for GPT, indicating that the decline in reading times was the largest after the first occurrence and getting less steep with further occurrences. However, this was not further supported by BF. There were no reliable interactions.

Discussion

The effect of syllable-level hyphenation on reading novel words was examined. The results revealed a repeated reading effect regardless of the Syllable Boundary Cue (SBC); reading got faster with repeated exposure to words similarly for 1st and 2nd grade children. We did not find evidence for phonology being more important than orthography even during the first encounter of the word, as indexed by the lack of facilitating effect of SBC in other measures than FFD. Furthermore, the role of phonology did not change with repetition, as indexed by the lack of an interaction between SBC and Index.

Even though the linear mixed-effects model for GPT showed a slow-down for hyphenated words, similarly to Häikiö et al. (2015), this finding was not backed up by the Bayesian analysis. Therefore, we do not want to make a case out of this effect. The lack of solid SBC effects in other measures than FFD goes against the findings of Häikiö et al. (2015), (2016) who witnessed a slowdown caused by hyphenation even for 1st graders. However, the current study used novel targets whereas Häikiö and colleagues used well-established words. Interestingly, the only facilitating effect of SBC was found in FFD. This pattern of results may be due to only targets being hyphenated, following the custom of Finnish reading instruction of novel words being hyphenated until the end of 2nd grade. Such signal may give rise to a different word reading strategy. There is evidence that when reader realizes that they need to make another fixation in order to process the word more efficiently, the initial fixation duration decreases (e.g., Bertram & Hyönä, 2003; Hyönä, 1995; Kliegl, Olson, & Davidson, 1983). This is exactly what we found as the hyphenated words elicited shorter first fixations. Even though our child participants rarely made single fixations in words, we believe the shorter first fixations are indicative of a similar change in the word reading strategy. When early Finnish readers encounter a word with hyphens, the initial fixation becomes shorter since the hyphen signals the word needs to be processed more extensively. As there was no overall effect of SBC in GD, the initial speed-up when entering the word was canceled out with longer following fixations, indicating more problems with the word processing for hyphenated words.

Given the pattern of the results, we think our findings indicate that even though phonology is important in reading novel words (e.g., Brusnighan et al., 2014), orthography also plays a substantial role. This is true even in a language with shallow orthography such as Finnish.

Interestingly, there was no effect of grade. This is likely due to the novel words being new for both grades. Even though the older children have more overall reading practice, when they encounter a new word for the first time, there is no advantage of more exposure.

Limitations of the current study

We did not monitor word learning as such, even though word learning is without question an integral part of novel word recognition. Because of this, we cannot be sure whether the findings regarding speedup with repetitive reading are indicative of lower level priming or proper deeper learning. In fact, the latter is unlikely as deeper orthographic and semantic learning requires several repetitions (e.g., Bowey & Muller, 2005; Elgort & Warren, 2014; Pellicer-Sánchez, 2015).

Theoretical and practical implications

Our findings indicate that even when an early reader might be able to process words using only phonological encoding, as is the case in languages with shallow orthography, the orthography is important as well. This may be compatible with the dual-route model of orthographic processing (Grainger & Ziegler, 2011) which posits that readers try to use all possible tools in word recognition including phonology and orthography. When words are hyphenated, one of these figurative tools is taken out of effective use. Because of this, we think that the routine use of hyphenation should be reconsidered in Finnish reading instruction, at least for proficient readers (i.e., fluent decoders). However, it may be the case that hyphenation is beneficial in breaking down very challenging words. Furthermore, some children may find hyphenated words subjectively easier to read even if the reading times are longer. Hyphenation may also be useful in specific exercises teaching spelling and syllabification skills. Finally, as the present study examined readers during the spring term, it remains to be seen whether hyphenation facilitates reading of very early readers or those with reading difficulties.

Disclosure statement

There is no conflict of interest for either of the authors. The ethical principles of the Declaration of Helsinki were followed. The Ethics Committee for Human Sciences of the University of Turku required no ethical review as all participants were voluntary and children's legal guardians signed a written informed consent form prior to the experiment.

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References

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*, 1–48. doi:10.18637/jss.v067.i01

Bertram, R., & Hyönä, J. (2003). The length of a complex word modifies the role of morphological structure: Evidence from eye movements when reading short and long Finnish compounds. *Journal of Memory and Language*, *48*, 615–634. doi:10.1016/S0749-596X(02)00539-9

Bowey, J. A., & Muller, D. (2005). Phonological recoding and rapid orthographic learning in third-graders' silent reading: A critical test of the self-teaching hypothesis. *Journal of Experimental Child Psychology*, *92*, 203–219. doi:10.1016/j.jecp.2005.06.005

Brusnighan, S. M., Morris, R. K., Folk, J. R., & Lowell, R. (2014). The role of phonology in incidental vocabulary acquisition during silent reading. *Journal of Cognitive Psychology*, *26*, 871–892. doi:10.1080/20445911.2014.965713

Elgort, I., & Warren, P. (2014). L2 vocabulary learning from reading: Explicit and tacit lexical knowledge and the role of learner and item variables. *Language Learning*, *64*, 365–414. doi:10.1111/lang.12052

Grainger, J., Lété, B., Bertand, D., Dufau, S., & Ziegler, J. C. (2012). Evidence for multiple routes in learning to read. *Cognition*, *123*, 280–292. doi:10.1016/j.cognition.2012.01.003

Grainger, J., & Ziegler, J. C. (2011). A dual-route approach to orthographic processing. *Frontiers in Psychology*, *2*, 54. doi:10.3389/fpsyg.2011.00054

Häikiö, T., Bertram, R., & Hyönä, J. (2016). The hyphen as a syllabification cue in reading bisyllabic and multisyllabic words among Finnish 1st and 2nd graders. *Reading and Writing*, *29*, 159–182. doi:10.1007/s11145-015-9584-x

Häikiö, T., Heikkilä, T. T., & Kaakinen, J. K. (2018). The effect of syllable-level hyphenation on reading comprehension: Evidence from eye movements. *Journal of Educational Psychology*, *110*, 1149–1159. doi:10.1037/edu0000261

Häikiö, T., Hyönä, J., & Bertram, R. (2015). The role of syllables in word recognition among beginning Finnish readers: Evidence from eye movements during reading. *Journal of Cognitive Psychology*, *27*, 562–577. doi:10.1080/20445911.2014.982126

Hautala, J., Aro, M., Eklund, J., Lerkkanen, M.-K., & Lyytinen, H. (2012). The role of letters and syllables in typical and dysfluent reading in a transparent orthography. *Reading and Writing*, *26*, 845–864. doi:10.1007/s11145-012-9394-3

Häyrinen, T., Serenius-Sirve, S., & Korkman, M. (2013). *Lukilasse 2: Lukemisen, kirjoittamisen ja laskemisen seulontatesti 1.–6. vuosiluokille. [Lukilasse 2: Screening test for reading, writing and calculus for 1st to 6th grades.]*. Helsinki, Finland: Hogrefe Psykologien Kustannus Oy.

Hothorn, T., Bretz, F., & Westfall, P. (2008). Simultaneous inference in general parametric models. *Biometric Journal*, *50*, 346–363. doi:10.1002/bimj.200810425

Hyönä, J. (1995). Do irregular letter combinations attract readers' attention? Evidence from fixation locations in words. *Journal of Experimental Psychology. Human Perception and Performance*, *21*, 68–81. doi:10.1037/0096-1523.21.1.68

Kliegl, R., Olson, R. K., & Davidson, B. J. (1983). On problems of unconfounding perceptual and language processes. In K. Rayner (Ed.), *Eye movements in reading: Perceptual and language processes* (pp. 333–343). New York, NY, United States: Academic Press.

Pellicer-Sánchez, A. (2015). Developing automaticity and speed of lexical access: The effects of incidental and explicit teaching approaches. *Journal of Spanish Language Teaching*, *2*, 126–139. doi:10.1080/23247797.2015.1104029

R Core Team, (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

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

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

Vauras, M., Mäki, H., Dufva, M., & Hämäläinen, S. (1995). *Diagnostiset testit 2: Kuullun ja luetun ymmärtäminen [Diagnostic tests 2: Listening and reading comprehension]*. Turku, Finland: University of Turku, Center for Learning Research.

Wechsler, D. (2003). *Wechsler intelligence scale for children–Fourth Edition (WISC-IV)*. San Antonio, TX: The Psychological Corporation.

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

Appendix

The models including final random structures for FFD, GD, GPT, and NoF are reported in Table A1, Table A2, Table A3, and Table A4, respectively.

Table A1. First fixation duration: Fixed effects from the model lmer(ffd~1+sbc*grade*index+sbc*grade*I(index^2)+(index|participant)+(1|item),data,REML = F)

	B	SE	t
(Intercept)	5.749	0.05293	108.609
SbcHYPHEN	−0.1898	0.05707	−3.325
Index	−0.06698	0.02447	−2.737
GradeG2	−0.07743	0.06496	−1.192
Index^2	0.004617	0.02506	0.184
SbcHYPHEN:Index	−0.05357	0.03136	−1.708
SbcHYPHEN:GradeG2	0.1084	0.07310	1.483
Index:GradeG2	0.02323	0.03160	0.735
SbcHYPHEN: Index^2	0.03667	0.03532	1.038
GradeG2:Index^2	−0.005076	0.03217	−0.158
SbcHYPHEN:Index:GradeG2	0.06193	0.04040	1.533
SbcHYPHEN:GradeG2:Index^2	−0.03090	0.04539	−0.681

Note: Dependent variable has been log-transformed. Sbc = Syllable boundary cue.

Table A2. Gaze duration: Fixed effects from the model lmer(gaze~1+sbc*grade*index+sbc*grade*I(index^2)+(index|participant)+(grade|item),data,REML = F)

	B	SE	t
(Intercept)	6.68516	0.11537	57.946
SbcHYPHEN	−0.02655	0.06882	−0.386
Index	−0.19461	0.02739	−7.106
GradeG2	−0.07823	0.14454	−0.590
Index^2	0.04768	0.03030	1.574
SbcHYPHEN:Index	0.01184	0.03774	0.314
SbcHYPHEN:GradeG2	0.12149	0.08808	1.379
Index:GradeG2	0.03945	0.03526	1.119
SbcHYPHEN: Index^2	0.01150	0.04253	0.270
GradeG2:Index^2	−0.01754	0.03882	−0.452
SbcHYPHEN:Index:GradeG2	0.04393	0.04866	0.903
SbcHYPHEN:GradeG2:Index^2	−0.03193	0.05466	−0.584

Note: Dependent variable has been log-transformed. Sbc = Syllable boundary cue.

Table A3. Go-past time: Fixed effects from the model lmer(gpt~1+sbc*grade*index+sbc*grade*I(index^2)+(index|participant)+(1|item),data,REML = F)

	B	SE	t
(Intercept)	6.956	0.1269	54.824
SbcHYPHEN	0.1246	0.05652	2.204
Index	−0.1565	0.02291	−6.834
GradeG2	−0.1420	0.1529	−0.929
Index^2	0.04957	0.02489	1.992
SbcHYPHEN:Index	0.008980	0.03119	0.288
SbcHYPHEN:GradeG2	−0.01744	0.07235	−0.241
Index:GradeG2	0.03040	0.02948	1.031
SbcHYPHEN: Index^2	0.0001274	0.03505	0.004
GradeG2:Index^2	0.01370	0.03190	0.429
SbcHYPHEN:Index:GradeG2	0.004765	0.04012	0.119
SbcHYPHEN:GradeG2:Index^2	−0.03057	0.04500	−0.679

Note: Dependent variable has been log-transformed. Sbc = Syllable boundary cue.

Table A4. Number of first-pass fixations: Fixed effects from the model glmer (nfix~1+sbc*grade*index+sbc*grade*I(index^2)+(index|participant)+(1|item),data,family = poisson)

	B	SE	z
(Intercept)	0.9648454	0.0888618	10.858
SbcHYPHEN	0.1077969	0.0602523	1.789
Index	−0.1102255	0.0236438	−4.662
GradeG2	0.0008754	0.0976351	0.009
Index^2	0.0368134	0.0269020	1.368
SbcHYPHEN:Index	0.0105352	0.0321674	0.328
SbcHYPHEN:GradeG2	0.0315543	0.0766587	0.412
Index:GradeG2	−0.0157048	0.0303547	−0.517
SbcHYPHEN: Index^2	0.0246628	0.0366295	0.673
GradeG2:Index^2	−0.0107141	0.0343629	−0.312
SbcHYPHEN:Index:GradeG2	0.0590702	0.0414236	1.426
SbcHYPHEN:GradeG2:Index^2	−0.0353848	0.0469170	−0.754

Note: Sbc = Syllable boundary cue.