Applied Psycholinguistics **38** (2017), 733–753
doi:10.1017/S0142716416000412

Syllables and morphemes in German reading development: Evidence from second graders, fourth graders, and adults

JANA HASENÄCKER and SASCHA SCHROEDER
Max Planck Institute for Human Development, Berlin

Received: November 23, 2015 Accepted for publication: August 30, 2016

ADDRESS FOR CORRESPONDENCE
Jana Hasenäcker, MPRG Reading Education and Development (REaD), Max Planck Institute for Human Development, Lentzeallee 94, Berlin 14195, Germany. E-mail: hasenaecker@mpib-berlin.mpg.de

ABSTRACT
Children have been found to use units such as syllables and morphemes in fine-grained reading processes, before they transition to a coarse-grained, holistic route. Which units they prefer at different stages in reading development is unresolved. The present study compares the use of syllables and morphemes. Second graders, fourth graders, and adults performed a lexical decision task on multimorphemic and monomorphemic words and pseudowords that were visually disrupted either syllable-congruent or syllable-incongruent (i.e., morpheme-congruent in multimorphemic items). Syllables turned out to be the preferred unit of fine-grained processing for second graders, while fourth graders also used morphemes when morphemes were emphasized by the presentation format. Moreover, the study supports the assumption that children rely more on fine-grained processing, while adults have more coarse-grained processing.

A central assumption of most models of reading acquisition is that children start out by decoding words on a letter-by-letter basis at first (Ehri, 1995; Grainger & Ziegler, 2011; Seymour, 2005; Share, 1995). They learn grapheme–phoneme correspondence (GPC) mappings and sound out words. As their reading skills develop and they gain more experience with written words, it is assumed that they become sensitive to intermediate-sized units until they are finally able to decode whole words directly “on sight.” For example, Seymour’s (2005) dual-foundation model proposes that reading develops in phases. It is thought to begin with simple alphabetic decoding using phonemes and advances to increasingly more complex structures, first centered around rimes, and in the last stage using syllables and morphemes. Equally, the multiple-route model of orthographic processing (Grainger & Ziegler, 2011) assumes that beginning readers start out by decoding words on a phonology-driven letter-by-letter basis (cf. Share, 1995) that leads them to two routes of orthographic processing: a fine-grained and a coarse-grained route. The main difference between the fine-grained and coarse-grained routes is the coding of letter positions: the fine-grained route is sensitive to ordered letter sequences, whereas letter coding in the coarse-grained route is position invariant. As a consequence, the coarse-grained route entails direct access from orthography to semantics via whole words, whereas the fine-grained route is tuned to detect frequently co-occurring letter sequences as functional units for word recognition. Both syllables and morphemes feature frequently co-occurring letter sequences and can thus be suspected to function as sensible intermediate-sized units that are detected in the fine-grained route. Albeit being formally very similar in terms of size and features of letter position coding, syllables and morphemes differ from each other in how they are defined and what type of information they encode. Syllables are phonologically defined and encode information about pronunciation. Morphemes are defined through the convergence of form and meaning, encoding lexical–semantic information. Syllables can thus be seen as being more closely associated with a phonological processing route, while morphemes constitute a more direct link between orthography and semantics. A very recent extension of the multiple-route model by Häikiö, Bertram, and Hyönä (2016) captures this relation by proposing a syllabic assembly mechanism as an intermediate stage between a phonological and a fine-grained route, thus predicting the use of syllables to chronologically precede the use of morphemes in reading development.

In a range of languages, empirical evidence has been put forward separately for the use of syllables and morphemes in reading development. Vast evidence shows that sensitivity to syllables, as a subdomain of phonological awareness, is a strong predictor for later reading ability (e.g., Wagner & Torgesen, 1987), measured, for example, by syllable counting or syllable segmentation tasks. In the process of reading, sensitivity to syllables has also been found early in children of different languages. For example, French Grade 5 readers show effects of syllable frequency (Chetail & Mathey, 2008) and syllable compatibility effects, that is, faster responses when a word was preceded by the corresponding syllable, have been found in syllable detection tasks with Grade 1, 3 and 5 children (Colé, Magnan, & Grainger, 1999; Maïonchi-Pino, Magnan, & Écalle, 2010) and in lexical decision tasks with sixth graders (Chetail & Mathey, 2012). The visual segmentation of a word in a position congruent with a syllable boundary (pa/per vs. p/aper) results in fewer word recognition errors for poor second-grade readers of English (Katz & Baldasare, 1983) and syllable-congruent coloring similarly speeds up poor second-grade readers of French, while it slows down good age-matched peers (Chetail & Mathey, 2009). Moreover, eye-tracking studies indicate that hyphenation at syllable boundaries is less disruptive than hyphenation within syllables for Finnish readers already by the end of first grade (Häikiö, Hyönä, & Bertram, 2015). This indicates that syllables are helpful units very early in reading acquisition and for dysfluent readers (see also Hautala, Aro, Eklund, Lerkkanen, & Lyytinen, 2012) and that in many languages syllables come into play very early in the course of reading acquisition.

There is also vast evidence that children use morphemes in word recognition. In lexical decision and naming tasks in a variety of languages, elementary school children have been found to respond faster and more accurately to multimorphemic compared to matched monomorphemic words (Italian: Marcolini, Traficante, Zocolotti, & Burani, 2011; French: Colé, Bouton, Leuwers, Casalis, & Sprenger-Charolles, 2011; Quémart, Casalis, & Duncan, 2012; English: Carlisle & Stone, 2003, 2005). Conversely, more false alarms and prolonged response times (RTs) in lexical decision were found in the presence of real morphemes in pseudowords, because they were mistaken as real words and thus harder to reject (Quémart et al., 2012). Those effects of morphology were found as early as in Grade 2 for French children, and a little later (around Grade 3) in Italian children. Moreover, masked morphological priming effects for suffixed words and nonwords have been reported for children in different languages from around Grade 3 onward (English: Beyersmann, Castles, & Coltheart, 2012; French: Beyersmann, Grainger, Casalis, & Ziegler, 2015; Casalis, Dusautoir, Colé, & Ducrot, 2009; Quémart, Casalis, & Colé, 2011). A Finnish eye-tracking study by Häikiö, Bertram, and Hyönä (2011) reports advantages from hyphenations in compounds only for slow second-grade readers, but not for their faster age-matched peers or Grades 4 and 6 readers. Therefore, as for syllables, there is general consensus that children use morphemes as units at some point in reading development; however, findings on when this happens diverge depending on the language studied.

It is important to note that only a few studies have more directly compared syllables and morphemes in reading (see Prinzmetal, Hoffman, & Vest, 1991, for a study with adults using an illusory conjunction paradigm). However, in order to refine models of reading acquisition, it is necessary to disentangle the relative importance of syllables and morphemes in word recognition and determine whether there is an order of their utilization in reading development. One study that has addressed the direct comparison between syllables and morphemes in child reading was undertaken by Colé et al. (2011) with French second and third graders. They used multimorphemic words in which the syllable and morpheme boundary do not coincide (e.g., *malade*). This is the case for multimorphemic words that have a suffix beginning with a vowel. The consonants at the end of the stem in these cases form a syllable unit with the suffix, because syllable division follows the maximal onset principle (Spencer, 1996), which states that the maximally possible number of consonants should be assigned to the onset of a syllable rather than to the end of the preceding syllable. Colé et al. (2011) exploited these cases to more directly compare the impact of syllabic segmentation (e.g., *ma lade*), morphological segmentation (*mal ade*) and morphological + 1 grapheme (*mala de*) to unsegmented low-frequency derivations (*malade*) in a reading task. Reading times were expected to be shorter if the segmentation is in line with the units that are activated in reading and longer when the segmentation destroys important units. The authors found that both second and third graders read words equally fast when they were segmented by a space into syllables or morphemes or were unsegmented. Readers were only slowed down by the morphological + 1 condition. These results point to flexible use of syllables, morphemes, and even whole words, at least for French Grade 2 and 3 readers in the reading of multimorphemic words.

Ziegler and Goswami (2005) emphasize in their psycholinguistic grain size theory that language-specific characteristics determine preferences for the use of certain units as linguistic characteristics of a language and its orthography may pose different demands on learners. Cross-linguistic differences in reading development have been attributed to orthographic transparency (Katz & Frost, 1992), syllable structure (Seymour, Aro, & Erskine, 2003), and morphological richness (Perfetti & Harris, 2013). Learners of opaque orthographies (e.g., English) might need longer to master GPC-based reading, while in transparent orthographies, like German or Finnish, solid reading skills can be achieved quickly by the use of GPC rules only (Wimmer & Goswami, 1994). As a consequence, learners of opaque orthographies can be assumed to profit considerably more from using bigger units, such as syllables or morphemes, because those tend to have more consistency in the way they are spelled and pronounced (Katz & Frost, 1992). However, languages also vary in the complexity of their syllable structure: for example, in Finnish and French syllable structure tends to be more simple, while the syllable structure of German and English is rather complex (Seymour et al., 2003). As Seymour et al. (2003) found, complex syllable structures tend to be more challenging for developing readers. Moreover, as the transparency of an orthography tends to be correlated with the morphological complexity of the language (Perfetti & Harris, 2013; Seidenberg, 2011), more transparent languages are often equipped with a richer and more productive morphology. For languages in which morphemes are very prominent, like German or Finnish, then, they suggest themselves as units in word recognition, despite the availability of smaller units. Considering the interplay of syllables and morphemes, languages also differ in the degree of convergence and interactions of the two units. In German, syllables and morphemes very often coincide. Moreover, suffixation usually does not affect stress assignment in the word, whereas in French, suffixes often draw the stress. The distinction between syllables and morphemes might therefore be less pronounced in German in comparison to French. Differences between languages in the structure of mappings between phonology, orthography, and meaning can produce differences in the sensitivity to certain sublexical units. Due to the described characteristics, German presents an interesting contrast to the languages in which development of syllables and morphemes as reading units has been studied so far, and different predictions can be made on the basis of its linguistic characteristics. In particular, the orthographic transparency together with complex syllable structure would predict prolonged reliance on graphemes throughout development. However, the morphological richness should act in favor of early advancement to morphemes. Finally, the prevalent convergence of morphemic units with syllabic units can be expected to also enhance reliance on syllables. Consequently, the relative importance of syllables and morphemes in reading development is unclear for this language and needs to be tested empirically.

To address the role of syllables and morphemes as reading units in German reading development, we adopted the methodology from the study by Colé et al. (2011), using a manipulation of the presentation format. Unfortunately, the study by Colé et al. (2011) focuses exclusively on multimorphemic words and does not reveal whether syllables are equally used in reading monomorphemic words. It is possible that a segmentation at the syllable boundary in monomorphemic words leads to even faster responses as it does not simultaneously destroy a morphemic structure. Therefore, we further extended the study design to monomorphemic words and made some slight changes to the paradigm. We included multimorphemic words with a syllabic segmentation (e.g., *FAH:RER*) and a morphological

https://doi.org/10.1017/S0142716416000412 Published online by Cambridge University Press

segmentation condition (*FAHR:ER*) in our study, just like Colé et al. (2011). In order to examine the use of syllables in multimorphemic words in comparison to that in monomorphemic words, we also included monomorphemic words that were segmented at the same positions as the multimorphemic words, namely, at the syllable boundary (syllable-congruent; e.g., *SPI:NAT*) or one letter after the syllable boundary (syllable-incongruent; *SPIN:AT*). Note that the latter parallels the morphological segmentation condition of the multimorphemic words, but in the case of the monomorphemic words cannot coincide with a morpheme boundary by definition (*–at* is not a German suffix). We hypothesized that word recognition would be easiest for readers in the disruption condition that puts emphasis on the functional unit they actually use, while other disruption positions should make reading harder. That is, if a reader uses only syllables as functional units, the syllable-congruent disruption condition should lead to faster word recognition compared to the incongruent disruption in both monomorphemic and multimorphemic words. However, if a reader uses morphemes as functional units, the syllable-incongruent disruption of multimorphemic words (e.g., *FAHR:ER*, thus being morpheme-congruent) should be faster than the syllable-congruent one, while this should not be the case for the monomorphemic words (*SPIN:AT*) as the resulting structure does neither map onto a phonological syllable nor onto a morpheme (but see Taft, 1979, 1986, for another possible structure called BOSS). Our study thus not only allows investigating the findings of Colé et al. (2011) for another language but also refines them due to the inclusion of monomorphemic words.

Another limitation of the study by Colé et al. (2011) is that no pseudowords were included, although those can also be informative concerning the use of syllables and morphemes in reading new items. Because children, especially those who have just started to read, are often confronted with a given written word for the first time, the use of syllables or morphemes in reading such a newly encountered word is of special interest with regard to the role of different units in reading development. Reading pseudowords most likely parallels the processes involved in reading new words. In the present study, we included pseudowords by employing a lexical decision task. Learners of transparent orthographies achieve basic reading skills with rather high accuracy rates very early in development (Seymour et al., 2003; Wimmer & Goswami, 1994), and silent reading, as required in the lexical decision task, is already natural to them. Therefore, a lexical decision is an adequate task to study processing also in beginning readers of German. The pseudowords included in the study matched the real words: they either did or did not feature an existing suffix (multimorphemic and monomorphemic pseudowords) and were also segmented syllable-congruent (e.g., *DOS:TOR*, *HEL:BER*) or syllable-incongruent (*DOST:OR*, *HELB:ER*), the latter again corresponding to a morpheme-congruent disruption for pseudowords featuring a suffix (*–er*). Considering the hypotheses for pseudowords, one has to keep in mind that, opposite of words, those have to be rejected in a lexical decision task. Syllable-congruent segmentation, encouraging the use of syllables, might help to "read through" the pseudoword faster than a segmentation that destroys this unit when readers rely on a phonological decoding strategy. It might thus allow a faster rejection relative to a syllable-incongruent segmentation, as evidence from English and Serbo-Croatian (Katz

& Feldman, 1981; Lima & Pollatsek, 1983) suggests. However, multimorphemic pseudowords have been found to be harder to reject (Burani, Marcolini, & Stella, 2002; Quémart et al., 2012), because morphemes as lexical–semantic units signal word status. Therefore, the syllable-incongruent segmentation of multimorphemic pseudowords (e.g., *HELB:ER*), which puts emphasis on the real suffix, might result in prolonged rejection times. Overall, including both mulimorphemic and monomorphemic words and pseudowords in our study provides a more extensive direct comparison of syllables and morphemes as functional units in reading.

To summarize, one of our main aims was to find out how the use of syllables and morphemes changes in the course of reading development in German. In order to investigate developmental differences, children at different stages in reading development were examined. Based on the previously mentioned findings on syllable and morpheme use in children, we decided to conduct the study with second and fourth graders. In accordance with the prediction of the multiple route model (Grainger & Ziegler, 2011) that developing readers use a phonological strategy in the beginning, we expected that younger children would be more inclined to make use of syllables in word recognition, because although those are intermediate-sized units, they are phonologically defined and thus more approximate to the phonological route (see Häikiö et al., 2016). Based on the developmental sequence outlined by Häikiö et al. (2016), older children, who had gained more reading experience, were expected to have moved away further from a phonological strategy and more toward an orthographic strategy using fine-grained processing with morphemes as functional units. In order to compare the processing strategies of readers that are still in the course of development to those of skilled readers, we also included a group of adults. The adults' processing thus serves as a reference point for the reading skills that the children should be achieving at some point in the future. Skilled readers should have access to both fine-grained and coarse-grained processing. Consequently, their reading strategy should depend on task demands. As coarse-grained processing, that is position invariant, is more robust to small changes in words that only affect a single sign (i.e., transposed or substituted letters: e.g., Forster, Davis, Schoknecht, & Carter, 1987; O'Connor & Forster, 1981), this would be a more beneficial strategy for the present task. It is therefore plausible that adults are able to adjust to this, being considerably less affected by the position of the disruption.

METHOD

Participants

Fifty-seven second-grade children were recruited from 10 elementary schools in the Berlin area. At the time of testing, the children were at the beginning of second grade, meaning they had received approximately 1 year of formal reading instruction. Permission for participation from the school administration and the children's parents was acquired prior to the experiment. Moreover, 20 fourth graders were recruited at the after-school care of one Berlin school. Permission from the after-school care and the children's parents was acquired before testing. Every child received a small gift and candy for his or her participation. Finally, 24 university students from the Berlin area participated for monetary reimbursement.

In order to ensure that participants showed age-appropriate reading behavior, each participant's reading fluency was assessed using the 1-min reading test for words and nonwords from the second edition of the Salzburg Reading and Spelling Test (Moll & Landerl, 2010). We used reading fluency percentile norm values of <3 as an indication that readers belonged to the 3% of the population at the lowest end of the reading fluency scale suffering from dyslexia. This applied to 6 second graders. Furthermore, we excluded one adult who reported having a history of dyslexia and two adults who reported having learned German as a second language later in life. As we aimed at investigating unimpaired reading, we excluded those participants. As a consequence, the study included 51 second graders (24 girls, M age = 6.9 years), 20 fourth graders (10 girls, M age = 9.5 years), and 21 university students (10 women, M age = 26.1 years). All remaining participants reported normal or corrected to normal vision and had German as their native language or second language acquired before the age of 6. As analyses for monolinguals and early bilinguals showed no differences, all children were included in the analyses.

Materials

Twenty-four multimorphemic words, consisting of a stem and a suffix, were selected from the childLex corpus (Schroeder, Würzner, Heister, Geyken, & Kliegl, 2015). Crucially, suffixes beginning with a vowel were chosen (*–er*, *–in*, *–ung*), because when they are combined with a stem, the syllable boundary does not correspond to the morpheme boundary, thus creating a special morphophonological case. The words were disrupted by inserting a colon (:) at the syllable boundary (syllable-congruent condition, e.g., *FAH:RER*) or one letter right of the syllable boundary (syllable-incongruent condition, *FAHR:ER*), which corresponds to the morpheme boundary in the multimorphemic words, thus being morpheme congruent for those. Moreover, 24 monomorphemic words were selected from the corpus and were also disrupted by a colon at the syllable-congruent (e.g., *SPI:NAT*) or syllable-incongruent (*SPIN:AT*) position. Mono- and multimorphemic words were matched on number of letters, number of syllables, frequency, bigram frequency, and neighbors (all $t < 1$, $p > .05$, see Table 1 for lexical statistics).

Moreover, 24 multimorphemic pseudowords were created by selecting multimorphemic words that were not in the stimulus set but had the same suffixes that were used in the word set (*–er*, *–in*, *–ung*). To create pseudowords, one letter in the stem was changed, such that the morphological structure remained due to the presence of the real suffix. Again, the items were disrupted syllable-congruent (e.g., *HEL:BER*) or syllable-incongruent/morpheme-congruent (*HELB:ER*). In addition, 24 monomorphemic words were chosen and one letter was changed in order to create monomorphemic pseudowords, which were again segmented at the syllable boundary (e.g., *DOS:TOR*) or one letter to its right (*DOST:OR*). Mono- and multimorphemic pseudowords were matched on number of letters, number

Table 1. *Lexical statistics of the word and pseudoword items*

	Monomorphemic				Multimorphemic			
	M	*SD*	Min	Max	*M*	*SD*	Min	Max
Words								
Letters	6.79	1.25	5.00	10.00	6.83	1.09	5.00	10.00
Syllables	2.29	0.55	2.00	4.00	2.25	0.44	2.00	3.00
Frequency[a]	24.13	28.07	0.81	121.92	28.77	50.72	0.31	217.95
Neighbors[b]	2.24	0.59	1.10	3.45	2.11	0.46	1.15	2.85
Bigram frequency[c]	30.11	5.21	22.4	43.17	31.19	4.63	22.96	41.23
Pseudowords								
Letters	6.54	1.02	5.00	9.00	7.00	1.38	5.00	11.00
Syllables	2.25	0.53	2.00	4.00	2.29	0.46	2.00	3.00
Neighbors[b]	2.42	0.58	1.05	3.65	2.35	0.44	1.75	3.45
Bigram frequency[c]	29.18	4.35	22.20	39.45	32.02	5.95	22.22	48.91

[a]Normalized type frequency (per million).
[b]Orthographic Levenshtein Distance 20.
[c]Summed bigram type frequency.

of syllables, bigram frequency, and neighbors (all $t < 1$, $p > .05$, see Table 1 for details). Finally, the pseudoword set and the word set were matched on these characteristics as well (all $t < 1$, $p > .05$, see Table 1).

Two lists were created from the final set of 48 words and 48 pseudowords, such that each stimulus appeared both in the syllable-congruent and the syllable-incongruent/morpheme-congruent condition across participants, but each participant only saw each stimulus in one of the conditions.

Procedure

The children were tested individually in a quiet room in their schools or in their after-school care. The adults were tested individually at the test center of the research institution. The experiment was run on a 15-in. laptop monitor with a refresh rate of 60 Hz. The stimuli were always presented in the center of the screen in white 20-point Courier New font on a black background. Each trial started with a 500-ms fixation cross, followed directly by a disrupted word or pseudoword. The word or pseudoword remained on the screen until a response was made by the participant. Participants were instructed to decide as quickly and as accurately as possible whether the presented stimulus was an existing German word or not while ignoring the colon in the stimulus. They were further instructed to indicate their decision by pressing the *D* or the *K* key on a standard keyboard, marked red and green. Eight practice trials with feedback (right or wrong answer) were given prior to the 96 experimental items. After half of the items, the participants had a break that was timed by the experimenter.

Table 2. *Mean (standard error) response times (ms) and error rates (%) to words*

	Monomorphemic		Multimorphemic	
	Syllable-Congruent	Syllable-Incongruent	Syllable-Congruent	Syllable-Incongruent/ Morpheme-Congruent
Response Times				
Grade 2	3150 (166)	3343 (177)	3411 (181)	3542 (188)
Grade 4	1563 (122)	1683 (131)	1556 (122)	1579 (123)
Adults	682 (52)	688 (52)	701 (53)	680 (52)
Error Rates				
Grade 2	10.93 (1.97)	19.76 (3.10)	18.58 (2.96)	19.71 (3.10)
Grade 4	12.47 (2.85)	10.83 (2.55)	10.80 (2.55)	7.01 (1.82)
Adults	3.56 (1.06)	3.20 (0.97)	1.97 (0.69)	1.96 (0.69)

RESULTS

Reaction times and error rates from the experiment were collected and analyzed separately for words and pseudowords. For the RT analysis, incorrect responses were removed from the analysis (15.80% for words, 15.80% for pseudowords), as were RTs below 200 ms or above 10000 ms (0.91% for words, 3.16% for pseudowords). The remaining RTs were then logarithmically transformed. Following Baayen and Milin (2010), model criticism based on a simple model including random effects for subject and item was used for further outlier trimming, excluding all data points with residuals exceeding 2.5 *SD* for the main analyses (2.32% for words, 1.95% for pseudowords). It should be noted that adults made very few errors, limiting the meaningfulness of the error rate analysis for adults. For reasons of completeness and because the children made more errors, we report error analyses too. The means and standard errors for words and pseudowords are presented in Tables 2 and 3 and illustrated in Figures 1 and 2, respectively.

Main data analyses were performed using linear mixed-effects models (Baayen, 2008; Baayen, Davidson, & Bates, 2008). A forward-selection procedure was used for model building, starting with a very simple model only including age group as a fixed effect and only adding predictors when they significantly improved model fit as indicated by comparison of the Bayes information criterion. The final model included morphological status (monomorphemic vs. multimorphemic), disruption position (syllable-congruent vs. syllable-incongruent/morpheme-congruent), age group (second graders vs. fourth graders vs. adults), and their interactions as fixed effects, and participants and items as random factors. The results for the overall effects tests using contrast coding and Type III sum of squares (using the Anova function in the car package) are summarized in Table 4. Post hoc comparisons were carried out using cell means coding, and single *df* contrasts using the glht function of the multcomp package (Hothorn, Bretz, & Westfall, 2008) were evaluated using a normal distribution.

Table 3. *Mean (standard error) response times (ms) and error rates (%) to pseudowords*

	Monomorphemic		Multimorphemic	
	Syllable-Congruent	Syllable-Incongruent	Syllable-Congruent	Syllable-Incongruent/ Morpheme-Congruent
	Response Times			
Grade 2	4079 (216)	4274 (226)	4242 (225)	4574 (243)
Grade 4	2208 (175)	2196 (174)	2239 (178)	2539 (202)
Adults	817 (63)	844 (65)	853 (66)	861 (66)
	Error Rates			
Grade 2	15.82 (2.39)	14.12 (2.19)	16.94 (2.51)	20.22 (2.86)
Grade 4	10.24 (2.44)	12.04 (2.76)	13.76 (3.05)	17.65 (3.69)
Adults	1.70 (0.62)	2.62 (0.85)	1.69 (0.61)	0.83 (0.38)

Words

The model fitted to the word data revealed a significant main effect of age group, indicating faster RTs with increasing age. Furthermore, age group interacted with morphological status as well as with disruption position. Decomposing the Age Group × Morphological Status interaction, post hoc contrasts showed that albeit second graders showed a numerical advantage for monomorphemic compared to multimorphemic words, this effect did not reach significance (ΔRT = 230 ms, $t = 1.72$, $p = .08$), and neither did the difference between monomorphemic and multimorphemic words in fourth graders and adults (Grade 4: ΔRT = 55 ms, $t < 1$, $p = .42$; adults: $\Delta RT = 5$ ms, $t < 1$, $p = .84$). The simple main effect of morphological status, however, was significantly different in second graders compared to fourth graders ($t = 4.29$, $p < .01$) and compared to adults ($t = 2.68$, $p < .01$), while fourth graders and adults did not differ significantly ($t = 1.57$, $p > .05$).

Decomposing the Age Group × Disruption Position interaction, it became clear that all children were slowed down significantly by the syllable-incongruent compared to the syllable-congruent condition (Grade 2: ΔRT = 162 ms, $t = 3.69$, $p < .01$; Grade 4: $\Delta RT = 72$ ms, $t = 2.21$, $p = .03$), while this was not the case for adults (ΔRT = 7 ms, $t < 1$, $p = .56$). The simple main effect of disruption position did not differ between second and fourth graders ($t < 1$, $p = .87$), but differed significantly between both second graders and adults ($t = 2.63$, $p < .01$) and fourth graders and adults ($t = 2.02$, $p = .04$).

There was no three-way interaction of morphological status, disruption position, and age group. A similar model was fitted to the error data. This mirrored the outcome of the RT model with a significant main effect of age group, indicating more accurate responses with increasing age. Age group also interacted with morphological status and with disruption position. Regarding the Age Group × Morphological Status interaction, post hoc contrasts showed that the direction of

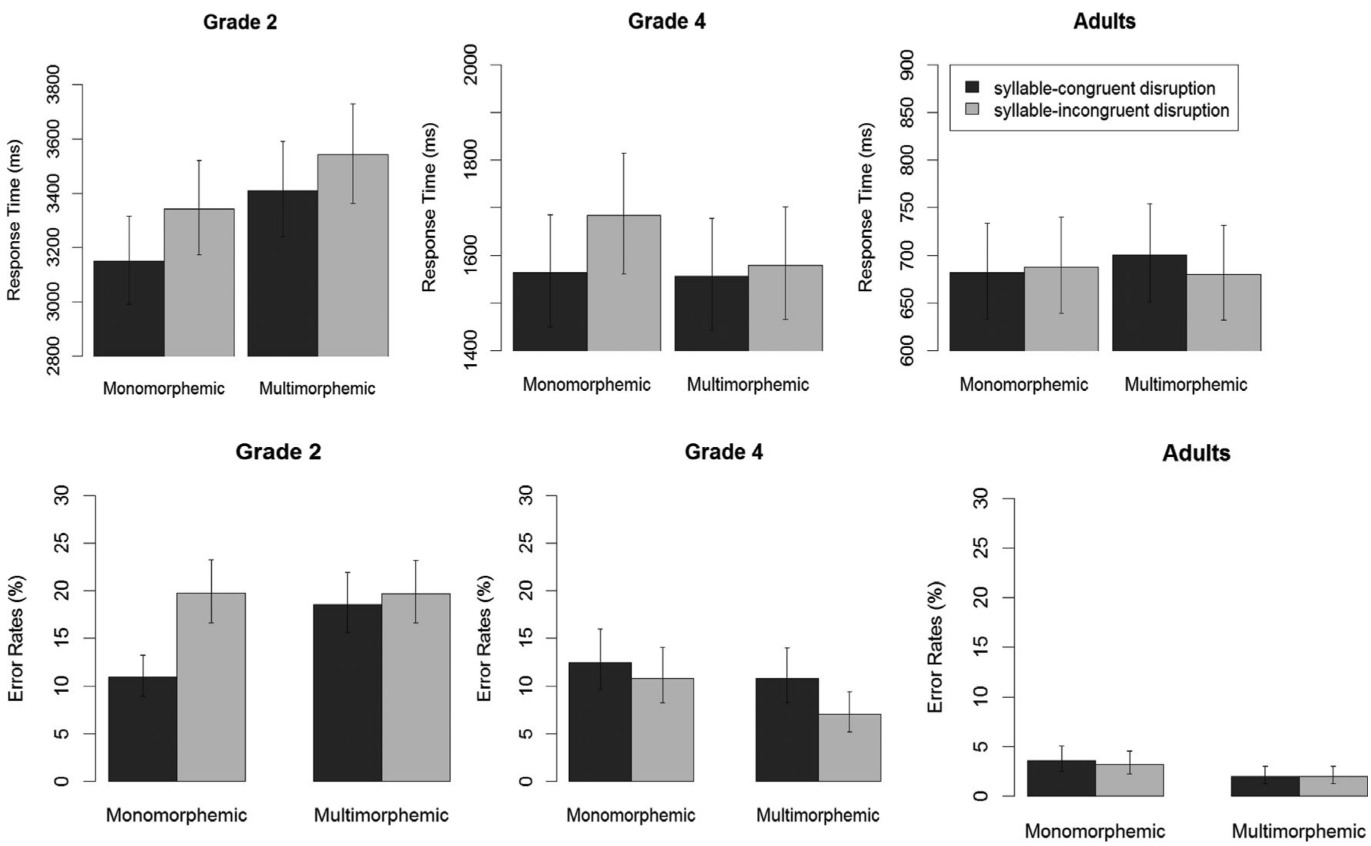

Figure 1. Mean response times (ms) and error rates (%) to words in the different conditions by age group. Error bars indicate standard errors.

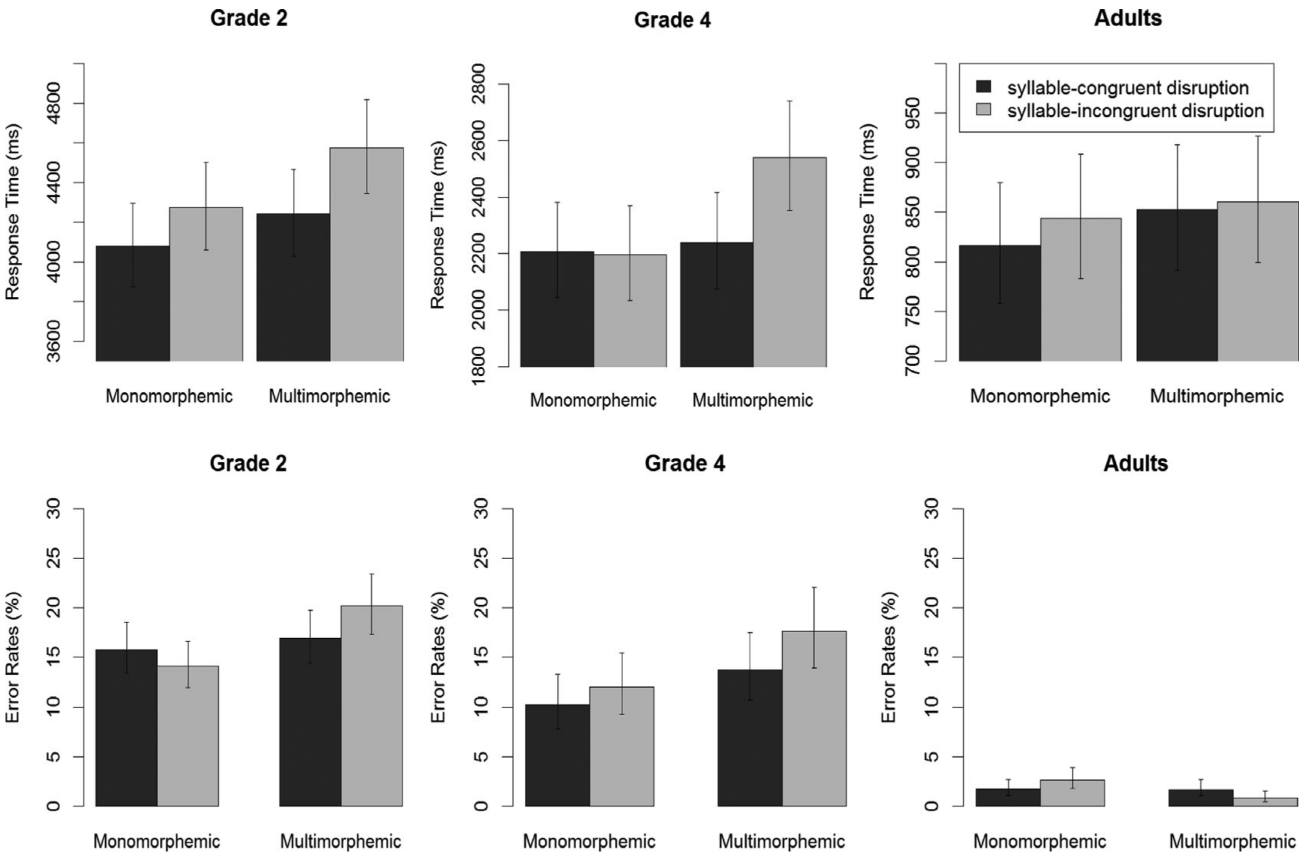

Figure 2. Mean response times (ms) and error rates (%) to pseudowords in the different conditions by age group. Error bars indicate standard errors.

Table 4. *Results from mixed-effect models with morphological status, disruption position, and age group as fixed effects and participant and item as random intercepts*

	χ^2			
	Words		Pseudowords	
	RT	Errors	RT	Errors
Fixed effects (*df*)				
Intercept (1)	8972.15*	192.37*	9157.91*	179.84*
Disruption position (3)	<1	<1	1.37	<1
Morphological status (1)	<1	1.95	<1	1.69
Age group (2)	417.43*	60.76*	405.31*	59.83*
Disruption Position × Morphological Status (1)	1.11	<1	<1	1.83
Disruption Position × Age Group (2)	7.37*	10.03*	3.54	1.11
Morphological Status × Age Group (2)	20.34*	11.80*	3.15	4.39
Disruption Position × Morphological Status × Age Group (2)	<1	1.35	8.23*	3.03
Random effects				
Participants	6565*	127*	6730*	226*
Items	509*	145*	432*	53*

Note: Tests are based on Type III sum of squares and χ^2 values with Kenward–Roger *df*. The numbers in parentheses are degrees of freedom. RT, Response time.

the morphological status effect differed significantly between second graders and fourth graders ($t = 2.74$, $p < .01$) and between second graders and adults ($t = 2.45$, $p = .01$). All other contrasts were not significant.

When decomposing the Age Group × Disruption Position, it became evident that second graders made fewer errors in the syllable-congruent disruption condition ($t = 3.57$, $p < .01$), while this was not the case for fourth graders ($t = 1.57$, $p = .12$) and adults ($t < 1$, $p = .86$).

Taken together, children's word recognition is impeded when syllables are visually disrupted, while adults are not affected differentially by syllable-congruent and syllable-incongruent/morpheme-congruent visual disruptions.

Pseudowords

RTs to pseudowords were analyzed as described above. A main effect of age group was found, indicating that RTs to pseudowords became faster with increasing age. This main effect was moderated by a three-way interaction of morphological status, disruption position, and age group.

Post hoc contrasts showed that for second-grade children, there was no interaction of morphological status and disruption position ($t = 1.09$, $p = .28$), nor a simple main effect of morphological status ($t = 1.44$, $p = .15$), but the simple main effect of disruption position was significant ($t = 4.62$, $p < .01$). This indicated slower responses to syllable-incongruent compared to syllable-congruent pseudowords ($\Delta RT = 264$ ms).

For fourth-grade children, there was an interaction effect of morphological status and disruption position ($t = 3.23$, $p < .01$). The effect of disruption position was only significant for multimorphemic words ($t = 4.29$, $p < .01$); that is, RTs to pseudowords disrupted at the syllable-incongruent position were longer when the pseudoword contained an existing morpheme ($\Delta RT = 298$ ms) and the segmentation was therefore morpheme congruent. There were no prolonged RTs to monomorphemic syllable-incongruent pseudowords ($t < 1$, $p = .85$).

Adults did not show a significant effect of neither morphological status ($t < 1$, $p = .42$) nor disruption position ($t = 1.17$, $p = .24$), nor the interaction of those ($t < 1$, $p = .52$).

Error rates to pseudowords were analyzed parallel to the RTs. The model yielded a significant main effect of age group only, indicating that error rates decreased with increasing age.

In summary, second graders were slower in rejecting pseudowords when the disruption was syllable incongruent, while fourth graders were only slowed down by syllable-incongruent (i.e., morpheme-congurent) disruptions of multimorphemic pseudowords, which were the morpheme-congruent cases. Adults were again not influenced by disruptions at all.

DISCUSSION

The present study examined second graders', fourth graders', and adults' use of syllables and morphemes as functional units in word recognition by using a lexical decision task with monomorphemic and multimorphemic words and pseudowords that were visually disrupted either in a syllable-congruent or a syllable-incongruent way (being morpheme-congruent in the case of mulitmorphemic words). Beginning and skilled readers were impacted differently by this disruption, implying that different units are preferred depending on the stage of reading development. Moreover, the effect of disruption position also differed for word recognition and pseudoword rejection in the different age groups. Second graders were faster when the disruption was syllable congruent in both word recognition and pseudoword rejection. For fourth graders, syllable-congruent disruptions were also faster in word recognition, but in pseudoword rejection, this was only the case for multimorphemic pseudowords. Together, this indicates that syllables facilitate word recognition for all children, while morphemes selectively impede the rejection of multimorphemic pseudowords in fourth graders. Adults were not affected differently by syllable-congruent and syllable-incongruent disruptions, neither in word recognition nor in pseudoword rejection.

Second-grade children in the present study responded faster when disruptions were congruent with the syllables (*SPI:NAT*, *FAH:RER*) than if they were not (*SPIN:AT*, *FAHR:ER*), regardless of the morphological status. Moreover, this pattern emerged for both words and pseudowords. In addition, second graders made fewer errors to words with syllable-congruent disruptions. Together, this shows that beginning readers of German can use syllables as units in reading. Moreover, the results indicate that word and pseudoword reading in young children is based on the same sublexical mechanism. This can be best interpreted as some kind of

https://doi.org/10.1017/S0142716416000412 Published online by Cambridge University Press

phonological restructuring into syllables prior to lexical access (Katz & Feldman, 1981) that helps the flow of reading, making it easier for beginning readers to "get through" the word or pseudoword. Taken together, the response pattern to words and pseudowords militates for the syllable as a salient grain size in German second graders' reading, while morphemic structure is still tedious.

Children in fourth grade in our study also showed facilitation from syllable-congruent compared to syllable-incongruent disruptions, albeit this effect did only emerge in the RTs, but not in the error rates. It is interesting that no facilitation from syllable-congruent disruptions in the monomorphemic pseudowords (*DOS:TOR*) was evident. The disruption position only made a difference in the multimorphemic pseudowords that featured a suffix, which was accentuated in the syllable-incongruent disruption (*HELB:ER*). Because pseudowords have to be rejected, the RTs can reflect not only actual reading processes but also rejection difficulty. Thus, the longer RTs to pseudowords that feature a suffix and are disrupted at the morpheme boundary, such that the suffix is highlighted, might point to a role of morphemes in reading. The prominences of syllables as functional units in word reading, but morphemes in pseudoword reading, is very interesting because it suggests that different processing mechanisms can be involved depending on lexicality and/or familiarity. When reading unfamiliar words, such as pseudowords, morphemes might be particularly consulted, as they aid breaking down and understanding unknown words (Bertram, Laine, & Virkkala, 2000). This draws on the different types of information that syllables and morphemes encode. The accentuation of the existing suffix in a pseudoword might thus result in longer attempts at ascribing meaning to the pseudoword, which finally fails (see Quémart et al., 2012). It can be assumed that fourth graders have already developed some sensitivity to suffixes as lexical–semantic units, but do not fully capitalize on morphemes as sublexical decoding units in words when they do not coincide with syllables. Together, results from words and pseudowords for fourth-grade readers indicate that in the course of reading development, sensitivity to morphemes emerges, while syllables do not lose their relevance as a grain size in fine-grained reading.

Turning to the results for the skilled adult readers in our study, we failed to find any effects of the disruption, in the case of both words and pseudowords. Certainly, this does not rule out the possibility that adults are sensitive to syllables and morphemes in word recognition, as has been evidenced by many studies with a variety of paradigms (e.g., for syllable effects, Carreiras, Álvarez, & De Vega, 1993; and Conrad & Jacobs, 2004; for a review of morphological effects, see Amenta & Crepaldi, 2012). Our results should be interpreted with caution in this regard with several considerations in mind. First, the words were very familiar to adults, as we chose them from a child corpus (childLex; Schroeder et al., 2015) with the developmental focus of the study in mind, and syllable and morpheme effects have been shown to diminish or even disappear with increasing word frequency (Colé et al., 1999; Marcolini et al., 2011). Second, the disruption we used (*:*) was very subtle for skilled readers, whose reading system is robust to some amount of impreciseness (e.g., Forster et al., 1987; O'Connor & Forster, 1981). Third, as the accentuation of certain units through the disruptions was not always helpful (e.g., *SPIN:AT*, leaving no sensible subunits, or *HELB:ER*, drawing the attention to the misleading existing suffix), adults might have ignored the manipulation

https://doi.org/10.1017/S0142716416000412 Published online by Cambridge University Press

altogether. Skilled readers thus showed less sensitivity to syllables and morphemes as sublexical units in the present study, which does not exclude their ability to rely on these grain sizes under task demands. However, in the present study, we suggest that they used a coarse-grained strategy that is more tuned to deal with the insertion of a single character at any position, because it uses position-invariant letter coding. After having arrived at a whole-word orthographic representation via the coarse-grained route, of course, morphological processing is possible. This supralexical morphological processing, however, does not assume the use of morphemes as ordered letter sequences, which we believe our manipulations tap into. The interpretation of the adult data in terms of skilled processing mechanisms is surely limited and needs to be investigated separately in future studies. In the present study, the skilled readers nevertheless serve as a control group to illustrate how the same materials should be processed by the end of reading development.

Our developmental results diverge from those of Colé et al. (2011), who reported equal use of syllables and morphemes in multimorphemic words already in second grade, while in our study syllables seemed to be the preferred units in word recognition still in fourth grade. The divergence in findings could possibly be ascribed to differences in the study design: for example, word frequencies might influence the magnitude of syllable and morpheme use (Colé et al., 1999; Marcolini et al., 2011), but are difficult to compare across the two studies. However, cross-linguistic differences affecting reading development (Seymour et al., 2003; Ziegler & Goswami, 2005) seem to present a more crucial factor for children. Particularly, in French, most common suffixes start with a vowel; thus, derivations typically have a morpheme-incongruent syllable structure. In German, in contrast, there are many suffixes starting with a vowel and many suffixes starting with a consonant, such that morpheme-congruent syllable structure is not an exception. Moreover, stress assignment in French is typically changed by suffixation, whereas in German, suffixation virtually never changes stress assignment. As a consequence, the distinction between syllables and morphemes might be less pronounced in German as compared to French, such that there is also less pressure to functionally separate them. The establishment of morphemes as separate functional units might only become urgent later for German children and in the beginning particularly for newly encountered words, when the amount of multimorphemic words that are learned through reading drastically increases between Grades 3 and 5 (Anglin, 1993; Segbers & Schroeder, 2016). Together with arguably less pronounced, but still effective differences in GPC consistency, syllable complexity, and morphological richness between German and French, this bears the possibility of a deviating developmental trajectory in the two languages.

The present study suggests that, at least for German, functional units of word recognition emerge in a sequential order, with syllables preceding morphemes. This is consistent with Häikiö et al.'s (2016) recent extension of the multiple-route model, which predicts the use of syllables to chronologically precede the use of morphemes in reading development. Nevertheless, comparing our findings to studies in other languages, especially the one by Colé et al. (2001), supports the assumptions of the psycholinguistic grain size theory (Ziegler & Goswami,

2005) that language-specific characteristics pose different demands on learners and determine cross-linguistic differences in the preference for certain reading units across reading development. This strongly suggests that cross-linguistic differences need to be taken into consideration by models of reading development. To base models on findings from a single language severely limits their generalizability across languages. Future studies should therefore aim at comparing the use of different functional units in reading development directly across languages, carefully selecting the languages under investigation with regard to their orthographic transparency, syllable structure, and morphological complexity. In addition, including younger and older children and reading skills as a moderating factor as well as the influence of other linguistic skills, such as phonological and morphological awareness, is highly desirable in order to investigate individual trajectories in future studies and thus advance models of reading development further.

In summary, by examining the use of syllabic and morphemic units in both mono- and multimorphemic words and also pseudowords in German, our results extend previous findings on children's use of ordered letter sequences in a fine-grained processing route. This allowed us, in an important extension to the findings by Colé et al. (2011) for French, to demonstrate developmental changes in the use of different functional units. We were able to show that the syllable comes first in development, and German second graders have a stronger preference for using syllables in word recognition, while morphemic structure is challenging for them. For the fourth graders, we did find use of both units in multimorphemic word recognition, indicating that fine-grained reading is still in practice by the end of elementary school and is flexible in regard to syllable versus morpheme use. While our data suggests that there is an order of acquisition, with syllables coming first and morphemes later, this does not need to be the case in all languages, as the comparison to Colé et al. (2011) demonstrates. Therefore, cross-linguistic developmental studies on that topic are highly desirable in order to further disentangle how language-specific characteristics influence the use of certain grain sizes at different stages in reading development.

APPENDIX A

Stimuli used in the experiment

Monomorphemic		Multimorphemic	
Syllable-Congruent	Syllable-Incongruent	Syllable-Congruent	Syllable-Incongruent
Words			
BAL:KON	BALK:ON	AH:NUNG	AHN:UNG
DIREK:TOR	DIREKT:OR	AL:TER	ALT:ER
FA:SCHING	FASCH:ING	ARBEI:TER	ARBEIT:ER

https://doi.org/10.1017/S0142716416000412 Published online by Cambridge University Press

APPENDIX A (*cont.*)

Words			
GAR:TEN	GART:EN	BÄ:RIN	BÄR:IN
HA:FEN	HAF:EN	DIE:BIN	DIEB:IN
KAPI:TEL	KAPIT:EL	ENKE:LIN	ENKEL:IN
KOM:PASS	KOMP:ASS	FAH:RER	FAHR:ER
KOM:POTT	KOMP:OTT	FLIE:GER	FLIEG:ER
MARZI:PAN	MARZIP:AN	FREUN:DIN	FREUND:IN
MO:TOR	MOT:OR	HEI:ZUNG	HEIZ:UNG
PORZEL:LAN	PORZELL:AN	HEL:DIN	HELD:IN
RE:GAL	REG:AL	KELLNE:RIN	KELLNER:IN
RE:KORD	REK:ORD	KLEI:DUNG	KLEID:UNG
RE:ZEPT	REZ:EPT	KÖNI:GIN	KÖNIG:IN
SCHAU:KEL	SCHAUK:EL	KRIE:GER	KRIEG:ER
SCHOKO:LADE	SCHOKOL:ADE	LAN:DUNG	LAND:UNG
SPIE:GEL	SPIEG:EL	MA:LER	MAL:ER
SPI:NAT	SPIN:AT	PILO:TIN	PILOT:IN
STU:DENT	STUD:ENT	PLA:NUNG	PLAN:UNG
TA:LENT	TAL:ENT	SIE:GER	SIEG:ER
TELE:FON	TELEF:ON	SPIE:LER	SPIEL:ER
TRAK:TOR	TRAKT:OR	WANDE:RUNG	WANDER:UNG
VUL:KAN	VULK:AN	WOH:NUNG	WOHN:UNG
ZIR:KUS	ZIRK:US	ZAH:LUNG	ZAHL:UNG
Pseudowords			
AL:KORD	ALK:ORD	AUBO:RIN	AUBOR:IN
BE:GEN	BEG:EN	EDE:LIN	EDEL:IN
DAU:SEN	DAUS:EN	FEIL:DIN	FEILD:IN
DOS:TOR	DOST:OR	HEI:GUNG	HEIG:UNG
EL:KASS	ELK:ASS	HEL:BER	HELB:ER
FA:MOTT	FAM:OTT	JU:GER	JUG:ER
FRAL:MENT	FRALM:ENT	LAH:RER	LAHR:ER
KA:DON	KAD:ON	LEIRE:RIN	LEIRER:IN
KON:BERT	KONB:ERT	LU:WIN	LUW:IN
KRI:KUS	KRIK:US	PFLO:GER	PFLOG:ER
LEMI:KON	LEMIK:ON	PINA:TIN	PINAT:IN
MARKE:LADE	MARKEL:ADE	RACH:TER	RACHT:ER
MAR:ZOR	MARZ:OR	REU:FUNG	REUF:UNG
MONA:TOR	MONAT:OR	ROD:NER	RODN:ER
PE:KAL	PEK:AL	RUL:DUNG	RULD:UNG
PELI:DAN	PELID:AN	SCHIL:TUNG	SCHILT:UNG
PRI:GAT	PRIG:AT	SCHOLDE:RUNG	SCHOLDER:UNG
PUL:DING	PULD:ING	SCHREU:BER	SCHREUB:ER
SCHAU:BEL	SCHAUB:EL	SONDA:TIN	SONDAT:IN
STIE:PEL	STIEP:EL	TE:GUNG	TEG:UNG
TANIS:MAN	TANISM:AN	TEI:NUNG	TEIN:UNG
TUR:FAN	TURF:AN	WARDE:RER	WARDER:ER
ZE:PENT	ZEP:ENT	WUR:TIN	WURT:IN
ZWIE:GEL	ZWIEG:EL	ZIE:DUNG	ZIED:UNG

https://doi.org/10.1017/S0142716416000412 Published online by Cambridge University Press

REFERENCES

Amenta, S., & Crepaldi, D. (2012). Morphological processing as we know it: An analytical review of morphological effects in visual word identification. *Frontiers in Psychology, 3*, doi:10.3389/fpsyg.2012.00232

Anglin, J. M. (1993). Vocabulary development: A morphological analysis. *Monographs of the Society for Research in Child Development, 58*(Serial No. 238).

Baayen, R. H. (2008). *Analyzing linguistic data*. Cambridge: Cambridge University Press.

Baayen, R. H., & Milin, P. (2010). Analyzing reaction times. *International Journal of Psychological Research, 3*, 12–28.

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 53*, 390–412. doi:10.1016/j.jml.2007.12.005

Bertram, R., Laine, M., & Virkkala, M. M. (2000). The role of derivational morphology in vocabulary acquisition: Get by with a little help from my friends. *Scandinavian Journal of Psychology, 41*, 287–296. doi:10.1111/1467-9450.00201

Beyersmann, E., Castles, A., & Coltheart, M. (2012). Morphological processing during visual word recognition in developing readers: Evidence from masked priming. *Quarterly Journal of Experimental Psychology, 65*, 1306–1326. doi:10.1080/17470218.2012.656661

Beyersmann, E., Grainger, J., Casalis, S., & Ziegler, J. C. (2015). Effects of reading proficiency on embedded stem priming in primary school children. *Journal of Experimental Child Psychology, 139*, 115–126. doi:10.1016/j.jecp.2015.06.001

Burani, C., Marcolini, S., & Stella, G. (2002). How early does morpholexical reading develop in readers of a shallow orthography? *Brain and Language, 81*, 568–586. doi:10.1006/brln.2001.2548

Carlisle, J. F., & Stone, C. A. (2003). The effects of morphological structure on children's reading of derived words in English. *Neuropsychology and Cognition, 22*, 27–52. doi:10.1007/978-1-4757-3720-2_2

Carlisle, J. F., & Stone, C. A. (2005). Exploring the role of morphemes in word reading. *Reading Research Quarterly, 40*, 428–449. doi:10.1598/rrq.40.4.3

Carreiras, M., Álvarez, C. J., & De Vega, M. (1993). Syllable-frequency and visual word recognition in Spanish. *Journal of Memory and Language, 32*, 766–780. doi:10.1006/jmla.1993.1038

Casalis, S., Dusautoir, M., Colé, P., & Ducrot, S. (2009). Morphological effects in children word reading: A priming study in fourth graders. *British Journal of Developmental Psychology, 27*, 761–766. doi:10.1348/026151008x389575

Chetail, F., & Mathey, S. (2008). The syllable frequency effect in visual recognition of French words: A study in skilled and beginning readers. *Reading and Writing, 22*, 955–973. doi:10.1007/s11145-008-9135-9

Chetail, F., & Mathey, S. (2009). Activation of syllable units during visual recognition of French words in Grade 2. *Journal of Child Language, 36*, 883–894. doi:10.1017/s0305000908009197

Chetail, F., & Mathey, S. (2012). Effect of syllable congruency in sixth graders in the lexical decision task with masked priming. *Scientific Studies of Reading, 16*, 537–549. doi:10.1080/10888438.2011.607480

Colé, P., Bouton, S., Leuwers, C., Casalis, S., & Sprenger-Charolles, L. (2011). Stem and derivational-suffix processing during reading by French second- and third-graders. *Applied Psycholinguistics, 33*, 97–120. doi:10.1017/s0142716411000282

Colé, P., Magnan, A., & Grainger, J. (1999). Syllable-sized units in visual word recognition: Evidence from skilled and beginning readers. *Applied Psycholinguistics, 20*, 507–532. doi:10.1017/s0142716499004038

Conrad, M., & Jacobs, A. (2004). Replicating syllable frequency effects in Spanish in German: One more challenge to computational models of visual word recognition. *Language and Cognitive Processes, 19*, 369–390. doi:10.1080/01690960344000224

Ehri, L. C. (1995). Phases of development in learning to read words by sight. *Journal of Research in Reading, 18*, 116–125. doi:10.1111/j.1467-9817.1995.tb00077.x

Forster, K. I., Davis, C., Schoknecht, C., & Carter, R. (1987). Masked priming with graphemically related forms: Repetition or partial activation? *Quarterly Journal of Experimental Psychology, 39*, 211–251. doi:10.1080/14640748708401785

Grainger, J., & Ziegler, J. C. (2011). A dual-route approach to orthographic processing. *Frontiers in Psychology, 2*, 1–12. doi:10.3389/fpsyg.2011.00054

Häikiö, T., Bertram, R., & Hyönä, J. (2011). The development of whole-word representations in compound word processing: Evidence from eye fixation patterns of elementary school children. *Applied Psycholinguistics, 32*, 533–551. doi:10.1017/S0142716411000208

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., 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, K., 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

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

Katz, L., & Baldasare, J. (1983). Syllable coding in printed-word recognition by children and adults. *Journal of Educational Psychology, 75*, 245–256. doi:10.1037/0022-0663.75.2.245

Katz, L., & Feldman, L. B. (1981). Linguistic coding in word recognition: Comparisons between a deep and a shallow orthography. In A. Lesgold & C. Perfetti (Eds.), *Interactive processes in reading*. Hillsdale. NJ: Erlbaum.

Katz, L., & Frost, R. (1992). The reading process is different for different orthographies: The orthographic depth hypothesis. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 67–84). Amsterdam: Elsevier North Holland Press.

Lima, S. D., & Pollatsek, A. (1983). Lexical access via an orthographic code? The Basic Orthographic Syllabic Structure (BOSS) reconsidered. *Journal of Verbal Learning and Verbal Behavior, 22*, 310–332. doi:10.1016/s0022-5371(83)90215-3

Maïonchi-Pino, N., Magnan, A., & Écalle, J. (2010). Syllable frequency effects in visual word recognition: Developmental approach in French children. *Journal of Applied Developmental Psychology, 31*, 70–82. doi:10.1016/j.appdev.2009.08.003

Marcolini, S., Traficante, D., Zoccolotti, P., & Burani, C. (2011). Word frequency modulates morpheme-based reading in poor and skilled Italian readers. *Applied Psycholinguistics, 32*, 513–532. doi:10.1017/s0142716411000191

Moll, K., & Landerl, K. (2010). *SLRT-II: Lese- und Rechtschreibtest: Weiterentwicklung der Salzburger Lese- und Rechtschreibtests (SLRT): Manual*. Bern, Switzerland: Verlag Hans Huber.

O'Connor, R. E., & Forster, K. I. (1981). Criterion bias and search sequence bias in word recognition. *Memory & Cognition, 9*, 78–92. doi:10.3758/bf03196953

Perfetti, C. A., & Harris, L. N. (2013). Universal reading processes are modulated by language and writing system. *Language Learning and Development, 9*, 296–316. doi:10.1080/15475441.1013.813828

Prinzmetal, W., Hofmann, H., & Vest, K. (1991). Automatic processes in word perception: An analysis from illusory conjunctions. *Journal of Experimental Psychology: Human Perception and Performance, 17*, 902–923. doi:10.1037/0096-1523.17.4.902

Quémart, P., Casalis, S., & Colé, P. (2011). The role of form and meaning in the processing of written morphology: A priming study in French developing readers. *Journal of Experimental Child Psychology, 109*, 478–496. doi:10.1016/j.jecp.2011.02.008

Quémart, P., Casalis, S., & Duncan, L. G. (2012). Exploring the role of bases and suffixes when reading familiar and unfamiliar words: Evidence from French young readers. *Scientific Studies of Reading, 16*, 424–442. doi:10.1080/10888438.2011.584333

Schroeder, S., Würzner, K.-M., Heister, J., Geyken, A., & Kliegl, R. (2015). *childLex: A lexical database for German read by children*. Manuscript submitted for publication.

Segbers, J., & Schroeder, S. (2016). How many words do children know? A corpus-based estimation of children's total vocabulary size. *Language Testing*. Advance online publication. doi:10.1177/0265532216641152

Seidenberg, M. (2011). Reading in different writing systems: One architecture, multiple solutions. In P. McCardle, J. Ren, & O. Tzeng (Eds.), *Dyslexia across languages: Orthography and the brain–gene–behavior link*. Baltimore, MD: Paul Brookes.

Seymour, P. H. K. (2005). Early reading development in European orthographies. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 296–315). London: Blackwell.

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

Spencer, A. (1996). *Phonology*. Oxford: Blackwell.

Taft, M. (1979). Recognition of affixed words and the word frequency effect. *Memory & Cognition, 7*, 263–272. doi:10.3758/bf03197599

Taft, M. (1986). Lexical access codes in visual and auditory word recognition. *Language and Cognitive Processes, 1*, 297–308. doi:10.1080/01690968608404679

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101*, 192–212. doi:10.1037/0033-2909.101.2.192

Wimmer, H., & Goswami, U. (1994). The influence of orthographic consistency on reading development: Word recognition in English and German children. *Cognition, 51*, 91–103. doi:10.1016/0010-0277(94)90010-8

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