Same Same, but Different: Word and Sentence Reading in German and English

SCHOLARONE™
Manuscripts

Running head: WORD AND SENTENCE READING IN GERMAN AND ENGLISH   1

Abstract

The current study compared eye fixation patterns during word and sentence processing in a

consistent and an inconsistent alphabetic orthography. German and English children as well

as adults matched on word reading ability read matched sentences while their eye fixation

behavior was recorded. Results indicated that German children read in a more small-unit

plodder-like style with more diligent first-pass reading and less re-reading. In contrast,

English children read in a more large-unit explorer-like style with a greater tendency to skip

words, and more regressions. Importantly, these cross-linguistic processing differences

largely persisted in the adult readers. Orthographic consistency thus influences both local

word recognition and global sentence processing, in developing and skilled readers.

Same same, but different: Word and sentence reading in German and English

Alphabetic orthographies differ with respect to the consistency of grapheme-phoneme-correspondences. A number of previous studies showed orthographic consistency to influence the rate and process of initial reading acquisition (e.g., Aro & Wimmer, 2003; Frith, Wimmer, & Landerl, 1998; Seymour, Aro, & Erskine, 2003). German is an alphabetic orthography with consistent grapheme-phoneme-correspondences, that is, one and the same grapheme typically receives the same pronunciation in different words (e.g., the vowel "a" is always pronounced in the same way in the German words *Karte, Fabel, Hand, Ball, Magier*). English, on the contrary, is an alphabetic orthography with much less consistent grapheme-phoneme-correspondences, that is, one and the same grapheme can be pronounced differently in different words (e.g., the vowel "a" is pronounced differently in the English words *card, fable, hand, ball, magician*).

The present study investigated cross-linguistic differences in eye movement patterns in word and sentence processing in these two alphabetic orthographies with different degrees of letter-sound consistency. We expected to find evidence for more small-unit processing in readers of the consistent German orthography, and more large-unit processing in readers of the inconsistent English orthography on both the local word and the global sentence processing level. In other words, in German readers, we expected to find an eye movement pattern which in dyslexia research has been described as a plodder reading style, while in English readers, we expected to find more of an explorer reading style (cf. Olson, Kliegl, Davidson, & Foltz, 1985).

Previous research on typically developing English-speaking readers of different ages showed consistently that eye fixation behavior changes with increasing reading experience: as reading skills increase, fixation durations and sentence reading times decrease, as does the number of fixations. While the probability for making more than one fixation on the same

word decreases, the probability that a word is not fixated but skipped in first pass increases (Blythe, Liversedge, Joseph, White, & Rayner, 2009; Buswell, 1922; McConkie et al., 1991; Rayner, 1985; Taylor, 1965; Vorstius, Radach, & Lonigan, 2014).

Another indicator of reading efficiency is how often a reader needs to move the eyes against the normal reading direction and make regressive right-to-left saccades. However, findings regarding the number or proportion of regressions and regression probability were less consistent: while some studies showed a decrease in the number of regressions during the first few years of reading instruction, constant numbers of regressions in higher grades, and again a decrease in adults (Buswell, 1922; Rayner, 1985), other studies showed a constant number of regressions among children of different ages, and a decrease for adults only (Blythe et al., 2009; McConkie et al., 1991; Taylor, 1965). Yet another pattern was reported by Vorstius and colleagues (2014) who found an *increase* in the proportion of inter-word regressions from grade 1 to 5. A likely explanation for these seemingly inconsistent results is that former studies have typically combined both intra- and inter-word regressions in their measures, even though these two types of regressions seem to have very different functions in reading. Intra-word regressions indicate careful first-pass word processing, while inter-word regressions, besides indicating processing difficulties due to grammatical and semantic complexities (e.g., Reichle, Warren, & McConnell, 2009), may indicate a more advanced and speeded reading style possibly with need for correction. A plausible assumption is that the number of intra-word regressions decreases in the course of reading development, and is replaced by an increased number of inter-word regressions so that the pooled rate of regressions appears to remain constant (cf. Radach, Günther, & Huestegge, 2012).

Crucially, the development of basic eye fixation characteristics in sentence or passage reading has been described in a remarkably similar way not only for English, but also for orthographies with more consistent grapheme-phoneme-correspondences (e.g., Finnish: Blythe, Häikiö, Bertram, Liversedge, & Hyönä, 2011; German: Huestegge, Radach, Corbic,

& Huestegge, 2009). In some sense this is surprising as reading acquisition was repeatedly

shown to proceed more slowly in inconsistent orthographies (e.g., Caravolas, Lervåg, Defior,

Seidlová Málková, & Hulme, 2013; Frith et al., 1998; Seymour et al., 2003). It thus appears

that basic eye fixation characteristics develop in a similar way for both consistent and

inconsistent orthographies when comparing the development *within* a single orthography,

consistent or inconsistent. However, given the differing rate of initial reading acquisition, it is

plausible to expect the development of eye fixation patterns to differ *between* consistent and

inconsistent orthographies.

In the context of cross-linguistic reading differences, it has been proposed that readers

of consistent orthographies preferentially use smaller units when reading, while readers of

inconsistent orthographies preferentially use larger units, which often help to disambiguate

the inconsistencies on the individual grapheme-phoneme level (Ziegler & Goswami, 2005).

There is indeed evidence corroborating this claim from a number of cross-linguistic studies on

single word recognition: While a stronger word length effect in readers of consistent

orthographies was interpreted to indicate their stronger reliance on systematic decoding

procedures (e.g., Ellis & Hooper, 2001; Goswami, Gombert, & Fraca de Barrera, 1998; Rau,

Moll, Snowling, & Landerl, 2015), stronger orthographic neighborhood (rime or body-N)

effects in readers of less consistent orthographies were taken to indicate more large-unit

processing on their part (e.g., Goswami et al., 1998; Ziegler, Perry, Ma-Wyatt, Ladner, &

Schulte-Körne, 2003). Importantly, it was claimed that differences in orthographic

consistency mainly affect the grain size of sublexical units on which an *initial*, serial, reading

strategy operates with *skilled* reading converging in different orthographies as the reading

process becomes increasingly lexicalized (de Jong, 2006). Nevertheless, some studies suggest

that such cross-linguistic differences are still evident in skilled adult readers (e.g., Paulesu et

al., 2000; Ziegler, Perry, Jacobs, & Braun, 2001), albeit to a lesser degree than in developing

readers (Rau et al., 2015).

It is important to note that previous studies on cross-linguistic processing differences primarily focused on local word recognition for single target items (e.g., Frith et al., 1998; Rau, Moeller, & Landerl, 2014), and those studies which have examined global sentence or text reading only did so in a single orthography (English: McConkie et al., 1991; Valle, Binder, Walsh, Nemier, & Bands, 2013; Vorstius et al., 2014; Finnish: Blythe et al., 2011; German: Hawelka, Gagl, & Wimmer, 2010; Huestegge et al., 2009; Trauzettel-Klosinski et al., 2010; Greek: Hatzidaki, Gianneli, Petrakis, Makaronas, & Aslanides, 2011; Italian: De Luca, di Pace, Judica, Spinelli, & Zoccolotti, 1999). In an attempt to compare global text processing across orthographies, Hutzler and Wimmer (2004) compared their own data on 13-year old German-speaking dyslexic and age-matched typical readers with data sets from two older studies, one with 12-year old Italian dyslexics and age-matched controls (de Luca et al., 1999), and one with 11-year old English-speaking dyslexics and age-matched controls (Lefton, Nagle, Johnson, and Fisher, 1979). Hutzler and Wimmer observed that mean fixation duration did not differ a great deal between the Italian dyslexics and controls in the study by de Luca and colleagues (290 vs. 230 ms, respectively), but was clearly more pronounced in their dyslexic sample than in their controls (360 vs. 190 ms, respectively). The authors attributed this finding to the higher complexity of syllables in German as compared to Italian. Of particular interest was the comparison of the proportions of regressions between orthographies (unfortunately, none of the studies specifies whether their regression measures pertain to intra- or inter-word regressions, or a composite of the two). The percentage of regressions of English-speaking readers in the study by Lefton and colleagues was higher for both dyslexic and control children (35 and 15%, respectively) than that of the two German-speaking groups in the Hutzler and Wimmer study (16 and 9%, respectively). In contrast, the Italian dyslexic and control children from the study by de Luca and colleagues each made 19% regressions. Hutzler and Wimmer suggested that the lower orthographic consistency of English may cause English-speaking children to regress more often than German or Italian

children. Importantly, however, comparisons made across different studies which are comparable neither in terms of reading material, nor in terms of participant age or reading ability are obviously suboptimal as the authors themselves do acknowledge.

Thus, it is crucial that eye fixation characteristics are compared between English and more consistent orthographies in direct cross-linguistic studies using an appropriate procedure for matching reading materials as well as participants. This was the main aim of the current study. To the best of our knowledge, this is the first study to directly compare eye fixation behavior between typically developing readers of a consistent and an inconsistent alphabetic orthography on both the local word processing, and the more global sentence processing level. We were interested in whether differences in orthographic consistency exert an influence beyond the level of pure word recognition. Several previous cross-linguistic studies compared German and English. This comparison seems appropriate because both languages differ with respect to orthographic consistency, but have common Germanic roots – a fact which permits the use of highly comparable target stimuli (i.e., cognates with nearly identical phonology, orthography, and semantics) although previous studies have only compared single word processing (e.g., Frith et al., 1998; Rau et al., 2015; Wimmer & Goswami, 1994; Ziegler et al., 2001). Since the two languages are furthermore comparable at the level of syntactic structure (at least for main clauses) (Landerl, in press), we constructed highly similar sentences which we presented to German- and English-speaking children and adults. The sentences mostly consisted of cognates and were highly comparable with regards to their syntactic structure (see Appendix).

Moreover, participants were carefully matched on basic word reading ability as indexed by their mean gaze duration for a set of short, high-frequency cognates included in the experimental reading material. Eye tracking allowed for online recording of sentence-reading processes as they occurred. We evaluated several local word-based variables which were computed over all words of the matched sentences, as well as global sentence-based

variables which were computed over all sentences. The advantage in analyzing cross-linguistic processing differences on the basis of single words is that the contrast between first-pass and second-pass processing may reveal important differences in the time-course of word recognition. Amongst the sentence-based parameters, the most important variables were those concerned with inter-word regressions because these can only be computed on the more global level.

We expected that differences in orthographic consistency should impact upon local word processing and global sentence processing alike. Generally speaking, we expected more small-unit processing in readers of German, and more large-unit processing in readers of English. According to Olson and colleagues' (1985) influential classification of dyslexic readers' eye movements, so called "plodders" show relatively few regressions between words and/or word-skipping, but move steadily forward in the text with relatively frequent forward saccades. At the other end of the dimension, "explorers" display more regressions to previous words, more word-skipping, and fewer progressive intra-word and inter-word movements. This classification was later applied to the distinction between developmental surface vs. developmental phonological dyslexia (Castles & Coltheart, 1993), with surface dyslexia corresponding to the plodders', and phonological dyslexia to the explorer's eye movement pattern (de Luca et al., 1999). It was further suggested that skilled readers can be divided into similar styles (Rayner, 1998), and it was indeed shown that more experienced adult readers skipped more words and made more regressions than less experienced adult readers (e.g., Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006; Rayner, Castelhano, & Yang, 2009). We were interested to evaluate the applicability of the plodder/explorer distinction in the context of cross-linguistic processing specificities.

More specifically, in local word processing, we expected a more plodder-like style for German-speaking readers to manifest in higher first-pass reading times (i.e., first fixation duration, gaze duration), a higher number of first-pass fixations, and a higher first-pass

refixation probability (note that these measures include intra-word regressions). At the same time, we expected a more explorer-like processing style for English-speaking readers to manifest in higher re-reading times and a higher number of re-reading fixations (these measures include inter-word regressions). Further, we expected this latter reading style to induce a higher skipping probability in English than in German readers.

In global sentence processing, we did not expect mean fixation duration to differ between orthographies, because German and English both have complex syllables (Seymour et al., 2003), and previously reported cross-linguistic differences in mean fixation duration were attributed to differences in syllabic complexity (Hutzler & Wimmer, 2004). As participants were carefully matched in terms of basic word reading ability, we also did not expect differences in total sentence reading time or the total number of fixations between German and English readers. Importantly however, as suggested by Hutzler and Wimmer, we expected that the lower orthographic consistency of English would cause English readers to regress more often than German readers. Since we expected possible cross-linguistic differences to diminish with increasing reading expertise, we expected to find cross-linguistic differences mainly in children.

Method

Participants

From a pool of 118 participants, we excluded nine children with word reading ability markedly below grade level (i.e., percentile rank < 16) as established by standardized reading fluency tests (German: SLRT-II by Moll & Landerl, 2010; English: TOWRE by Torgesen, Wagner, & Rashotte, 1999). Out of the remaining 109 participants, we identified 25 German-English pairs of children matched on gaze duration for a number of short, high-frequency words featuring in the sentences as well as 16 matched German-English pairs of adults. The ten words used for participant matching were German-English cognates[1] (i.e., words with identical meaning and highly similar orthography and phonology in both languages) with

comparable mean CELEX frequency counts (mean frequency per 1 million words in German and English was 117 (SD=102) and 129 (SD=84), respectively, $t(9) = 1.02$, $p = .33$). Basic word reading ability as defined by mean gaze duration for these short, high-frequency cognates was thus comparable for German and English children as well as adults. However, please note that this resulted in a tendency for English children to be older than German children with a significant advantage in terms of length of school attendance (see Table 1).

Please insert Table 1 here

We chose not to match participants on the basis of their performance on the standardized reading fluency tests (SLRT II/TOWRE) because the tests are not readily comparable in terms of reading material, testing time, print font, and time of standardization. However, as evident in Table 1, percentile ranks for both the word- and the nonword reading lists of the two tests were largely comparable between children of the two orthographies.

All participants were native speakers of their respective languages and had normal or corrected-to-normal vision. German children were recruited from local elementary schools and attended grades 2, 3, and 4. English children were recruited during a summer sports camp and had completed grades 3, 4, 5, or 6 at the time of testing. Informed consent was provided by the parents, and children received a small gift in appreciation of their participation. The participating adults were students of the German and English universities at which the experiment took place.

Apparatus

Eye fixation behavior was recorded using an EyeLink 1000 tower mount eye tracker in Germany, and an EyeLink 1000 desktop mount eye tracker in England (SR Research, Ottawa). Single line sentences were presented one after the other using the unproportional font Courier New (bold, font size 14 pt) in black against a white background on the center line

of a 20-inch monitor in both countries. Standard 9-point calibration at the beginning of the

experiment ensured a maximum average error of 1.0 degrees across the nine calibration

points.

Materials and Design

There were 72 sentences in total. In the context of a different research question, 24 of

the sentences contained a nonword and were excluded from current analyses since we were

interested in the processing of normal sentences. The vast majority of the words featuring in

the sentences were German-English cognates. Sentences were also closely matched between

the two languages with regard to syntactic structure and semantic content (e.g., *Die Äpfel in*

der Box sind rot und grün / The apples in the box are red and green – see Appendix for the

complete set of sentences)[2]. The average number of words per sentence was numerically

slightly higher for English, but this difference was statistically not significant (8.2 vs. 7.7,

$t(94) = 1.25$, $p = .22$). In turn, the average number of letters per word was slightly higher for

German (4.8 vs. 4.4, $t(94) = 2.92$, $p < .01$). Importantly, however, the average number of

letters/sentence did not differ between the two orthographies (36.6 vs. 35.2, $t(94) = .88$, $p =$

.38).

Procedure

After completion of the standardized test of reading fluency measuring the number of

words and nonwords read correctly within a specified time, participants were seated in front

of the screen with their forehead against a forehead rest to restrict head movements.

Participants were instructed to read the sentences aloud at their normal speed without making

mistakes and to immediately look at a small cross at the lower right corner of the screen after

having completed reading. Viewing distance was 70 cm from the monitor in a dimly lit room.

We chose to have participants read the sentences aloud to promote careful reading and

to be able to check reading accuracy. Thus, we had full control over participant's reading, and

decided not to include comprehension questions (which are often used to ensure careful

reading in silent reading paradigms) as this would have increased testing time, particularly for

the young and inexperienced readers.

Reading errors were corrected by the experimenter only during the six practice

sentences. At the beginning of each sentence, participants had to fixate a small smiley on the

left side of the center line. When fixation of the smiley was verified by the eye-tracking

device within 5000 ms from trial onset, the following sentence was presented with its first

word appearing at the location of the smiley. When no fixation on the smiley was detected,

the 9-point calibration cycle was repeated. Sentences disappeared as soon as the small cross at

the bottom right of the screen was fixated. The experimenter noted down reading errors.

Additionally, a voice recorder was used to double-check critical passages. Child participants

could take a break whenever needed. The experimental session lasted between half an hour

for adult subjects and an hour for the youngest children.

Results

Data screening

Fixations shorter than 80 ms were discarded from analyses. Words which received no

fixation in first-pass reading were also excluded from analyses for all local measures of

processing time. Words/sentences were excluded when there were problems with calibration

accuracy, when a participant failed to immediately fixate the small cross at the bottom of the

screen after having finished reading, or when a participant did not finish reading the whole

sentence. For local word-based parameters, we also excluded the first and the last word of

each sentence (for a similar procedure, see Vorstius et al., 2014), and words which were not

read correctly. Finally, the ten words used for participant matching were excluded from all

word-based analyses. For local word-based parameters, data loss was 10.3% and 11.0% for

German and English children, and 5.5% and 4.9% for German and English adults,

respectively. For global sentence-based parameters, data loss was 7.7% and 8.3% for German

and English children, and 4.7% and 4.6% for German and English adults, respectively.

Analyses

Because of large overall differences in processing speed between children and adults, possible cross-linguistic differences in local word processing and global sentence processing were examined separately for the two age groups. We ran linear mixed effects (LME) models in case of continuous measures and generalized LME with a binomial error distribution and the logit as link function for probability data (i.e., refixation probability, skipping probability, and regression probability measures). For the analyses of local measures, we computed models with orthography as a fixed factor, word length as a covariate, participants, sentences and words as crossed random effects and a range of word-based parameters as dependent variables. The dependent variables of the analyses of the global measures were sentence-based parameters. Therefore, we excluded words as a random effect and used mean word length of sentences as a covariate in the analyses of the global measures. The covariates word length and mean word length were centered prior to data analyses. LME and generalized LME models were run using R (R Development Core Team, 2015) and the R package lme4 (Bates, Maechler, Bolker, & Walker, 2015). We used likelihood ratio tests to derive *p*-values for the fixed effect orthography. Moreover, we corrected for multiple testing using the Benjamini-Hochberg method. Table 2 provides an overview and definitions of all dependent variables. An important concept which helps understanding of the different measures is that of a "pass". The first pass reflects the first encounter with a word before the eyes move away from it to either a previous or subsequent word.

Please insert Table 2 here

Children

Table 3 shows the mean scores for local and global eye-tracking parameters for German and English children and Table 4 presents the LME models for these parameters.

Please insert Tables 3 and 4 here

Local word-based variables.

The results for local word-based variables presented in the upper part of Table 3 are fully in line with our expectations. Gaze durations in first-pass reading were reliably higher in German as compared to English children. For first fixation durations the expected difference was significant prior to controlling for multiple testing (as evident from the confidence interval), reflecting a tendency in the expected direction. On the other hand, mean re-reading time was significantly higher in English children. Taken together, this resulted in comparable total word reading times for the two orthographies. The same held for the number of fixations: while the number of first-pass fixations was significantly higher in German, and the number of re-reading fixations reliably higher in English children, the total number of fixations did not differ between the two groups. In line with this, the probability of refixating a word during first-pass reading was reliably higher in German than in English children, while general refixation probability did not differ between orthographies. Finally, and also consistent with our expectations, skipping probability was significantly more pronounced in English than in German children.

Global sentence-based variables.

The lower part of Table 3 shows the statistical details for the cross-linguistic comparison of global sentence-based variables for children. As expected, mean fixation duration, total sentence reading time and total number of fixations did not differ between children reading the two orthographies. Importantly, and in line with our expectations, English children made significantly more inter-word regressions than German children, both

in absolute and in relative terms (i.e., when taking into consideration the overall number of

saccades).

Adults

Table 5 shows the mean scores for local and global eye-tracking parameters for

German and English children and Table 6 presents the LME models for these parameters.

Please insert Tables 5 and 6 here

Local word-based variables.

The eye-tracking parameters of local word-processing variables for adults are shown

in the upper part of Table 5. Unlike in children, gaze duration and re-reading time did not

differ between German and English adults, and neither (in line with the data from children)

did total reading time. Nevertheless, results were comparable to those of children for number

of fixations: German adults made reliably more fixations than English adults in first-pass

reading but (unlike in children), the number of re-reading fixations and the total number of

fixations did not differ between German and English adults. However, it should be noted that

the expected difference for the total number of fixations was significant prior to controlling

for multiple testing (as evident from the confidence interval), reflecting a tendency in the

expected direction. Consistent with findings on children, the probability of refixating a word

in first-pass was significantly higher in German than in English adults, whereas general

refixation probability did not differ between adult readers of the two orthographies. Finally,

and again consistent with the results for children, skipping probability was significantly

higher in English than in German adults.

Global sentence-based variables.

The lower part of Table 5 shows the mean scores for global sentence-processing

variables for German and English adults. Consistent with findings from children, German and

WORD AND SENTENCE READING IN GERMAN AND ENGLISH   15

English adult readers showed similar mean fixation duration, total sentence reading time, and

total number of fixations. Unlike to what was found in children, English adults did not make

significantly more inter-word regressions than German adults either in absolute or relative

terms. However, it is important to note that for the relative number of regressions (i.e.,

percentage of regressions) the difference was significant prior to controlling for multiple

testing. Thus, there was a tendency for a higher percentage of inter-word regressions in

English than in German adults.

Discussion

To date, sentence processing has primarily been studied within a specific orthography,

meaning that previous cross-linguistic comparisons are not robust. The current study aimed to

investigate cross-linguistic differences in eye fixation behavior for local word and global

sentence processing in a direct comparison of German and English. A strength of the study

was that participating children and adults were matched on word reading ability and the

reading material itself was also matched across orthographies. Because of differences in

orthographic consistency between German and English, we expected more small-unit

processing in readers of German, and more large-unit processing in readers of English on both

the word and the sentence level, with more pronounced cross-linguistic differences in children

than in adults.

In children, the results perfectly met our expectations. Thanks to careful participant

matching, the overall processing outcome for both the local word, and the global sentence

level did not differ between children of the two orthographies: they neither differed in mean

fixation duration, total sentence reading time, nor in the total number of fixations they made.

However, as predicted, there were distinct cross-linguistic differences with respect to how this

equal outcome was achieved. German children took more time to process both words and

sentences in first-pass reading and consequently needed less time for re-reading. In contrast,

English children were faster in initial processing, but made more regressions between words,

and also took more re-reading time. In line with this, first-pass refixation probability was higher for German than for English children, whereas general refixation probability was comparable between them. Also in line with their generally more diligent first-pass processing, the probability of skipping a word was less pronounced in German than in English children.

Thus, children of both orthographies did not differ in the *outcome* of sentence processing. However, the *way* in which they achieved this highly similar outcome differed in an important way: German children appeared to put more effort in careful first-pass processing, a trend which was reflected in their higher initial processing times, higher number of first-pass fixations, higher first-pass refixation probability, and lower skipping probability. This approach of rather slow and meticulous first-pass reading makes frequent regressions and long re-reading times unnecessary. English children, on the contrary, appeared to read in a more fragmented way. They were much more likely to skip words and took less time for thorough first-pass processing. They did, however, regress much more often and took more time for second-pass reading than the German children. It should be noted that the higher skipping rate in English as compared to German children could partly be attributed to the fact that the English words were slightly shorter than the German words. Given the well-established link between word length and skipping probability (e.g., Rayner, 1998), this may appear quite likely. However, analyses accounted for word length. Thus, the finding that skipping probability was about twice as high in English than in German children reflects a genuine difference in processing mode.

Importantly, the children in our study were carefully matched on basic word reading ability, and their equivalent total sentence processing times corroborates their highly comparable level of reading skill. The cross-linguistic differences we found are therefore reflecting genuinely different approaches to word and sentence processing rather than different levels of reading skill. It is however noteworthy that the German children of our

sample tended to be younger than the English children, and thus had received less reading

instruction to attain this comparable level of reading skill. Having said that, the finding that

reading development progresses at a slower rate in inconsistent than in consistent

orthographies has been shown many times before (e.g., Caravolas et al., 2013; Frith et al.,

1998; Seymour et al., 2003; Thorstad, 1991).

The plodder-explorer distinction as described for dyslexic readers by Olson and

colleagues (1985) fits remarkably well with the orthography-dependent differences in

sentence processing observed in the current study. Within this view, German children

exhibited a plodder, and English children an explorer style of reading. If we concede that

surface dyslexia is more often reported in consistent orthographies (Bergmann & Wimmer,

2008; de Luca et al., 1999), while phonological dyslexia is more often reported in the

inconsistent English orthography (Castles & Coltheart, 1993), the more frequent reading style

associated with dyslexia in consistent versus inconsistent orthographies appears to reflect the

reading style shown by typically developing readers of their respective orthography:

Importantly, the distinctive style of reading as shown by German and English children reflects

the characteristics of the orthography they are reading. Thus, the more small-unit plodder-like

reading pattern of the German children is a useful strategy, since small-unit grapheme-

phoneme correspondences are reasonably consistent in German. At the same time, the more

large-unit explorer-like reading pattern of the English children is a reading strategy well

adapted to the fact that the English orthography is highly inconsistent on the small-unit

grapheme-phoneme level but much more consistent on the larger-unit syllable level (Treiman,

Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995).

Reading mode was aloud in order to promote careful reading. We do believe that this

oral reading procedure equally enhanced reading for meaning, but since we did not ask

comprehension questions, we cannot be sure that all children fully comprehended all of the

sentences. Having said this, we would like to highlight again that the sentences were

constructed so that children with two or more years of reading instruction should be able to understand them, that the words in the sentences were, on average, of very high frequency in both languages, and that all children were average or above average readers.

Reading without meaning would be a particular concern for the German sample as their orthography would allow them to decode the regular letter sequences with minimal comprehension. However, there is ample evidence that even very young readers do show lexical access during reading in consistent orthographies evidenced by effects of lexicality and word frequency (e.g., Burani, Marcolini, & Stella, 2002; Grande, Meffert, Huber, Amunts, & Heim, 2011; Pagliuca, Arduino, Barca, & Burani, 2008; Rau et al., 2014). In particular, effects of word familiarity (comparing high-frequency words, low-frequency words and nonwords) were found for German readers of different ages (Grades 2, 3, 4 and young adults) in an analysis based on a subset of target words from the current sentence reading paradigm (Rau et al., 2015). This finding corroborates our assumption that children mostly did comprehend the presented reading material.

Notably, the considerable cross-linguistic processing differences we found in children were at least partly still present in adult readers (for whom limitations in comprehension are certainly no concern). Although German and English adults did not differ to quite the same extent as children, German adults made more fixations and more refixations in first-pass reading, while English adults showed a higher skipping probability and a tendency towards a higher percentage of regressions. It thus appears that differences in orthographic consistency mainly affect the sublexical unit size upon which *initial* reading is reliant (cf. de Jong, 2006). The fact that the reading process differed less clearly between German and English adults than between German and English children can be taken as evidence that *skilled* reading converges in different orthographies as the reading process becomes increasingly lexicalized (cf. de Jong, 2006). Nevertheless, the overall *pattern* of a more diligent small-unit plodder-

WORD AND SENTENCE READING IN GERMAN AND ENGLISH 19

like reading style in readers of German, and a more context-seeking large-unit explorer-like reading style in readers of English is largely still evident in experienced readers.

Taken together, the present study revealed that German and English children as well as adults of comparable reading ability process highly similar reading material with identical overall processing outcomes, but fundamentally different reading styles. While German readers exhibit more of a plodder, English readers exhibit more of an explorer reading style, reflecting the specificities of consistent and inconsistent orthographies, respectively. This indicates that orthographic consistency exerts an influence on reading development and skilled reading.

References

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using Eigen and S4. *Retrieved from http://CRAN.R-project.org/package=lme4*

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society, 57*, 289–300.

Bergmann, J., & Wimmer, H. (2008). A dual-route perspective on poor reading in a regular orthography: Evidence from phonological and orthographic lexical decisions. *Cognitive Neuropsychology, 25*, 653-676.

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.

Blythe, H. I., Häikiö, T., Bertam, R., Liversedge, S. P., & Hyönä, J. (2011). Reading disappearing text: Why do children refixate words? *Vision Research, 51*, 84-92.

Blythe, H. I., Liversedge, S. P., Joseph, H. S. S. L., White, S. J., & Rayner, K. (2009). Visual information capture during fixations in reading for children and adults. *Vision Research, 49*, 1583-1591.

Buswell, G. T. (1922). *Fundamental reading habits: A study of their development*. Chicago, IL: University of Chicago Press.

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

Castles, A., & Coltheart, M. (1993). Varieties of developmental dyslexia. *Cognition, 47*, 149-180.

De Luca, M., di Pace, E., Judica, A., Spinelli, D., & Zoccolotti, P. (1999). Eye movement patterns in linguistic and non-linguistic tasks in developmental surface dyslexia. *Neuropsychologia, 37*, 1407-1420.

WORD AND SENTENCE READING IN GERMAN AND ENGLISH   21

De Jong, P. F. (2006). Units and routes of reading in Dutch. *Developmental Science, 9*, 441-442.

Duyck, W., Desmet, T., Verbeke, L. P., & Brysbaert, M. (2004). WordGen: A tool for word selection and nonword generation in Dutch, English, German, and French. *Behavior Research Methods, Instruments, & Computers, 36*, 488-499.

Ellis, N. C., & Hooper, A. M. (2001). Why learning to read is easier in Welsh than in English: Orthographic transparency effects evinced with frequency-matched tests. *Applied Psycholinguistics, 22*, 571-599.

Frith, U., Wimmer, H., & Landerl, K. (1998). Differences in phonological recoding in German- and English-speaking children. *Scientific Studies of Reading, 2*, 31-54.

Goswami, U., Gombert, J. E., & Fraca de Barrera, L. (1998). Children's orthographic representations and linguistic transparency: Nonsense word reading in English, French, and Spanish. *Applied Psycholinguistics, 19*, 19-52.

Grande, M., Meffert, E., Huber, W., Amunts, K., & Heim S. (2011). Word frequency effects in the left IFG in dyslexic and normally reading children during picture naming and reading. *NeuroImage, 57*, 1212-1220.

Hatzidaki, A., Gianneli, M., Petrakis, E., Makaronas, N., & Aslanides, I. M. (2011). Reading and visual processing in Greek dyslexic children: An eye-movement study. *Dyslexia, 17*, 85-104.

Hawelka, S., Gagl, B., & Wimmer, H. (2010). A dual-route perspective on eye movements of dyslexic readers. *Cognition, 115*, 367-379.

Huestegge, L., Radach, R., Corbic, D., & Huestegge, S. M. (2009). Oculomotor and linguistic determinants of reading development: A longitudinal study. *Vision Research, 49*, 2948-2959.

Hutzler, F., & Wimmer, H. (2004). Eye movements of dyslexic children when reading in a regular orthography. *Brain and Language, 89*, 235-242.

Landerl, K. (in press). Reading acquisition in German language. In C. Perfetti & L.

Verhoeven (Eds.) *Reading acquisition across languages and writing systems*.

Cambridge: Cambridge University Press.

Lefton, L. A., Nagle, R. J., Johnson, G., & Fisher, D. F. (1979). Eye movement dynamics of

good and poor readers: Then and now. *Journal of Reading Behavior, 11*, 319-328.

McConkie, G. W., Zola, D., Grimes, J., Kerr, P. W., Bryant, N. R., & Wolff, P. M. (1991).

Children's eye movements during reading. In J. Stein (Ed.), *Vision and visual dyslexia*

(pp. 251-262). London: The Macmillan Press.

Moll, K., & Landerl, K. (2010). *Lese- und Rechtschreibtest (SLRT II)*. Bern: Huber.

Olson, R. K., Kliegl, R., Davidson, B. J., & Foltz, G. (1985). Individual and developmental

differences in reading disability. In G. E. McKinnon & T. G. Waller (Eds.), *Reading

research: Advances in theory and practice* (pp. 1-6). New York: Academic Press.

Pagliuca, G., Arduino, L. S., Barca, L., & Burani, C. (2008). Fully transparent orthography,

yet lexical reading aloud: The lexicality effect in Italian. *Language and cognitive

processes, 23*, 422-433.

Paulesu, E., McCrory, E., Fazio, F., Menoncello, L., Brunswick, N., Cappa, S. F., ... & Frith,

U. (2000). A cultural effect on brain function. *Nature Neuroscience, 3*, 91-96.

R Development Core Team. (2015). R: A Language and Environment for Statistical

Computing. Vienna, Austria: R Foundation for Statistical Computing. *Retrieved from

http://www.R-project.org/*

Radach, R., Günther, T., & Huestegge, L. (2012). Blickbewegungen beim Lesen,

Leseentwicklung und Legasthenie. *Lernen und Lernstörungen, 1*, 185-204.

Rau, A. K., Moeller, K., & Landerl, K. (2014). The transition from sublexical to lexical

processing in a consistent orthography: An eye-tracking study. *Scientific Studies of

Reading*, *18*, 224-233.

WORD AND SENTENCE READING IN GERMAN AND ENGLISH   23

Rau, A. K., Moll, K., Snowling, M. J., & Landerl, K. (2015). Effects of orthographic

   consistency on eye movement behavior: German and English children and adults

   process the same words differently. *Journal of Experimental Child Psychology, 130,*

   92-105.

Rayner, K. (1985). The role of eye movements in learning to read and reading disability.

   Remedial and Special Education, 6, 53-60.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of

   research. *Psychological Bulletin, 124*, 372-422.

Rayner, K., Castelhano, M. S., & Yang, J. (2009). Eye movements and the perceptual span in

   older and younger readers. *Psychology and Aging, 24*, 755-760.

Rayner, K., Reichle, E. D., Stroud, M. J., Williams, C. C., & Pollatsek, A. (2006). The effect

   of word frequency, word predictability, and font difficulty on the eye movements of

   young and older readers. *Psychology of Aging, 21*, 448-465.

Reichle, E. D., Warren, T., & McConnell, K. (2009). Using EZ Reader to model the effects of

   higher level language processing on eye movements during reading. *Psychonomic

   bulletin & review*, *16*(1), 1-21.

Seymour, P. H. K., Aro, M., & Erskine, J. M. (2003). Foundation literacy acquisition in

   European orthographies. *British Journal of Psychology, 94*, 143-174.

Taylor, S. E. (1965). Eye movements while reading: Facts and fallacies. *American

   Educational Research Journal, 2*, 187-202.

Thorstad, G. (1991). The effect of orthography on the acquisition of literacy skills. *British

   Journal of Psychology, 82*, 527-537.

Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (1999). *Test of word reading efficiency

   (TOWRE).* Austin, Texas: pro.ed.

Trauzettel-Klosinski, S., Koitzsch, A. M., Dürrwächter, U., Sokolov, A. N., Reinhard, J., &

Klosinski, G. (2010). Eye movements in German-speaking children with and without

dyslexia when reading aloud. *Acta Ophthalmologica, 88*, 681-691.

Treiman, R., Mullennix, J., Bijeljac-Babic, R., & Richmond-Welty, E. D. (1995). The special

role of rimes in the description, use, and acquisition of English orthography. *Journal

of Experimental Psychology: General*, *124*(2), 107.

Valle, A., Binder, K. S., Walsh, C. B., Nemier, C., & Bands, K. E. (2013). Eye movements,

prosody, and word frequency among average- and high-skilled second-grade readers.

School Psychology Review, 42, 171-190.

Vorstius, C., Radach, R., & Lonigan, C. J. (2014). Eye movements in developing readers: A

comparison of silent and oral sentence reading. *Visual Cognition, 22*, 458-485.

Wimmer, H., & Goswami, U. (1994). The influence of orthographic consistency on reading

development: Word recognition in English and German children. *Cognition, 51*, 91-

103.

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.

Ziegler, J. C., Perry, C., Jacobs, A. M., & Braun, M. (2001). Identical words are read

differently in different languages. *Psychological Science, 12*, 379-384.

Ziegler, J. C., Perry, C., Ma-Wyatt, A., Ladner, D., & Schulte-Körne, G. (2003).

Developmental dyslexia in different languages: Language-specific or universal?

Journal of Experimental Child Psychology, 86, 169-193.

WORD AND SENTENCE READING IN GERMAN AND ENGLISH

Footnotes

[1] The German/English cognates used for participant matching were: Kuh/cow, rot/red, Tee/tea, vier/four, Mond/moon, Bier/beer, Musik/music, sieben/seven, Hotel/hotel, Mitte/middle.

[2] Mean CELEX frequencies were 12.631 per million over all German words of the sentences, and 13.749 per million over all English words of the sentences, a differences which was statistically not significant, $t(694) = .51$, $p = .61$. The words not listed in CELEX (mostly names such as Eric, Suzie, etc.) made up 8.9% of all German, and 8.4% of all English words.

WORD AND SENTENCE READING IN GERMAN AND ENGLISH

26

Table 1

Participant Matching Between the Two Orthographies.

	German Means (SD) [range]	English Means (SD) [range]	t	p
Children				
Age in months	109 (12) [93 – 135]	116 (13) [94 - 135]	0.97[a]	.06[c]
School attendance in months	31 (12) [17 - 47]	48 (12) [28 - 71]	5.05[a]	< .001[c]
Gaze duration short high-frequency words in ms	317 (69) [178 - 481]	310 (79) [148 - 503]	0.34[a]	.73
Percentile rank word reading	79 (17) [38 - 97]	67 (20) [36 - 99]		
Percentile rank nonword reading	74 (19) [34 - 98]	75 (21) [29 - 99]		
Adults				
Age in months	297 (54) [240 - 456]	279 (48) [228 - 432]	0.99[b]	.33
Gaze duration short high-frequency words in ms	239 (45) [177 - 357]	244 (55) [182 - 335]	0.27[b]	.79
Percentile rank word reading	61 (20) [24 - 96]	55 (20) [23 - 80]		
Percentile rank nonword reading	57 (18) [18 - 81]	78 (18) [25 - 91]		

Note. [a] *df* = 48. [b] *df* = 30. [c] two-tailed.

WORD AND SENTENCE READING IN GERMAN AND ENGLISH

27

Table 2

Dependent variables and their definitions.

Local word-based variables	
<u>Measures of first-pass processing</u>	
Mean first fixation duration (ms)	Duration of the first fixation on a word
Mean gaze duration (ms)	Summed duration of all fixations on a word in first pass
Mean number of first-pass fixations	Number of fixations occurring in first pass
First-pass refixation probability	Probability of making more than one fixation in first pass
Skipping probability	Probability of not fixating a word in first pass
<u>Measures of second-pass processing</u>	
Mean re-reading time (ms)	Summed duration of all fixations on a word after the first pass
Mean number of re-reading fixations	Number of fixations occurring after the first pass
<u>Measures of total processing</u>	
Mean total word reading time (ms)	Summed duration of all fixations on a word (i.e., gaze duration + re-reading time)
Mean total number of fixations	Number of all fixations on a word (i.e., no. of first-pass fixations + no. of re-reading fixations)
General refixation probability	Probability of making more than one fixation in either first-pass processing or re-reading

WORD AND SENTENCE READING IN GERMAN AND ENGLISH   28

Global sentence-based variables

Mean fixation duration/sentence (ms)	Mean fixation duration over all fixations on a sentence
Total sentence reading time (ms)	Summed duration of all fixations on a sentence
Total number of fixations/sentence	Number of all fixations on a sentence
Mean number of interword regressions/sentence	Number of between-word backward eye movements in a sentence
Mean percentage of interword regressions/sentence	Percentage of between-word backward eye movements in a sentence in relation to all eye movements

Table 3

Means (SDs in parenthesis) of Local Word Processing and Global Sentence Processing

Parameters for German and English Children.

Local word-based variables	German (*n* = 25)	English (*n* = 25)
Measures of first-pass processing		
Mean first fixation duration (ms)	268 (32)	251 (28)
Mean gaze duration (ms)	396 (70)	339 (51)
Mean number of first-pass fixations	1.44 (0.26)	1.18 (0.19)
First-pass refixation probability	.33 (.12)	.23 (.07)
Skipping probability	.06 (.05)	.14 (.06)
Measures of second-pass processing		
Mean re-reading time (ms)	98 (43)	152 (68)
Mean number of re-reading fixations	.37 (.16)	.54 (.27)
Measures of total processing		
Mean total word reading time (ms)	494 (93)	491 (102)
Mean total number of fixations	1.81 (0.38)	1.72 (0.42)
General refixation probability	.50 (.14)	.47 (.13)
Global sentence-based variables		
Mean fixation duration/sentence (ms)	271 (27)	262 (28)
Total sentence reading time (ms)	4008 (876)	3952 (1205)
Total number of fixations/sentence	14.95 (3.16)	15.05 (3.93)

Mean number of interword regressions/sentence	1.27 (0.5)	2.46 (1.04)
Mean percentage of interword regressions/sentence	.08 (.03)	.16 (.06)

WORD AND SENTENCE READING IN GERMAN AND ENGLISH   31

Table 4

Means (SDs in parenthesis) of Local Word Processing and Global Sentence Processing

Parameters for German and English Adults.

Local word-based variables	German (*n* = 25)	English (*n* = 25)
Measures of first-pass processing		
Mean first fixation duration (ms)	241 (23)	242 (25)
Mean gaze duration (ms)	284 (25)	281 (32)
Mean number of first-pass fixations	1.06 (0.12)	0.89 (0.10)
First-pass refixation probability	.17 (.05)	.12 (.04)
Skipping probability	.12 (.07)	.25 (.08)
Measures of second-pass processing		
Mean re-reading time (ms)	31 (37)	37 (26)
Mean number of re-reading fixations	.14 (.15)	.14 (.12)
Measures of total processing		
Mean total word reading time (ms)	316 (47)	319 (36)
Mean total number of fixations	1.20 (0.22)	1.02 (0.20)
General refixation probability	.27 (.11)	.22 (.08)
Global sentence-based variables		
Mean fixation duration/sentence (ms)	243 (26)	239 (26)
Total sentence reading time (ms)	2404 (444)	2207 (429)
Total number of fixations/sentence	10.08 (1.85)	9.37 (1.68)

Mean number of interword regressions/sentence	0.68 (0.61)	1.01 (0.63)
Mean percentage of interword regressions/sentence	.06 (.05)	.11 (.05)

WORD AND SENTENCE READING IN GERMAN AND ENGLISH   33

Table 5

Results of the LME for Local Word Processing and Global Sentence Processing Parameters for

German and English Children.

Local word-based variables	Coefficient	Estimate	*SE*	*t-*/*z*-value	χ^2	*p*-unc.	*p*-cor.
Measures of first-pass processing							
Mean first fixation duration (log)							
	Intercept	5.47	0.02	332.13	-	-	-
	Orthography	0.07	0.03	2.15	4.46	.035	.058
	Word length	0.02	<0.01	6.03	34.63	<.001	<.001
	Orthography × Word length	0.00	0.01	-0.63	0.39	.532	.647
Mean gaze duration (log)							
	Intercept	5.76	0.02	234.83	-	-	-
	Orthography	0.18	0.05	3.81	13.39	<.001	<.001
	Word length	0.09	0.01	15.03	158.52	<.001	<.001
	Orthography × Word length	0.02	0.01	1.84	3.34	.068	.109
Mean number of first-pass fixations							
	Intercept	1.40	0.04	36.35	-	-	-
	Orthography	0.29	0.07	3.99	14.38	<.001	<.001
	Word length	0.19	0.01	20.01	224.98	<.001	<.001
	Orthography × Word length	0.06	0.01	3.92	15.26	<.001	<.001
First-pass refixation probability (log odds)							
	Intercept	-0.94	0.10	-9.80	-	-	-
	Orthography	0.57	0.19	3.01	8.51	.004	.007
	Word length	0.41	0.02	20.05	253.83	<.001	<.001
	Orthography × Word length	0.08	0.04	2.16	4.62	.032	.055
Skipping probability (log odds)							
	Intercept	-3.46	0.13	-27.59	-	-	-
	Orthography	-0.91	0.24	-3.78	13.56	<.001	<.001
	Word length	-0.70	0.04	-15.66	226.14	<.001	<.001
	Orthography × Word length	0.04	0.08	0.49	0.22	.641	.721

Measures of second-pass processing Mean re-reading time (ms)							
	Intercept	132.41	9.84	13.46	-	-	-
	Orthography	-51.54	19.13	-2.69	6.95	.008	.016
	Word length	21.31	2.37	9.00	71.07	<.001	<.001
	Orthography × Word length	-16.53	4.15	-3.99	15.60	<.001	<.001
Mean number of re-reading fixations							
	Intercept	0.50	0.04	13.76	-	-	-
	Orthography	-0.18	0.07	-2.58	6.35	.012	.022
	Word length	0.10	0.01	11.44	106.86	<.001	<.001
	Orthography × Word length	-0.09	0.01	-5.79	32.42	<.001	<.001
Measures of total processing Mean total word reading time (log)							
	Intercept	6.03	0.03	192.05	-	-	-
	Orthography	0.09	0.06	1.45	2.07	.150	.233
	Word length	0.11	0.01	15.31	160.83	<.001	<.001
	Orthography × Word length	-0.01	0.01	-0.47	0.22	.639	.721
Mean total number of fixations							
	Intercept	1.91	0.07	29.29	-	-	-
	Orthography	0.12	0.12	0.92	0.85	.357	.487
	Word length	0.29	0.01	19.97	231.46	<.001	<.001
	Orthography × Word length	-0.03	0.02	-1.15	1.32	.251	.365
General refixation probability (log odds)							
	Intercept	0.16	0.11	1.52	-	-	-
	Orthography	0.16	0.21	0.75	0.56	.453	.600
	Word length	0.42	0.02	19.33	243.45	<.001	<.001
	Orthography × Word length	0.03	0.04	0.71	0.49	.483	.621
Global sentence-based variables Mean fixation duration/sentence (log)							
	Intercept	5.57	0.01	387.94	-	-	-

						p-unc.	p-cor.
	Orthography	0.04	0.03	1.23	1.49	.223	.334
	Word length	0.02	0.01	3.26	10.11	.001	.003
	Orthography × Word length	0.00	0.01	0.11	0.01	.912	.946
Total sentence reading time (log)							
	Intercept	8.21	0.04	213.73	-	-	-
	Orthography	0.05	0.08	0.68	0.45	.500	.625
	Word length	0.12	0.02	5.13	24.50	<.001	<.001
	Orthography × Word length	0.02	0.05	0.33	0.11	.744	.817
Total number of fixations/sentence							
	Intercept	15.02	0.57	26.19	-	-	-
	Orthography	0.04	1.15	0.04	0.00	.971	.971
	Word length	1.57	0.40	3.98	15.06	<.001	<.001
	Orthography × Word length	0.07	0.79	0.09	0.01	.925	.946
Mean number of interword regressions/sentence							
	Intercept	1.86	0.12	15.19	-	-	-
	Orthography	-1.18	0.25	-4.81	19.75	<.001	<.001
	Word length	0.04	0.08	0.55	0.30	.581	.688
	Orthography × Word length	-0.03	0.16	-0.19	0.04	.850	.910
Mean percentage of interword regressions/sentence (log odds)							
	Intercept	0.12	0.01	17.68	-	-	-
	Orthography	-0.08	0.01	-5.81	26.01	<.001	<.001
	Word length	-0.01	<0.01	-2.22	4.82	.028	.051
	Orthography × Word length	0.01	0.01	0.94	0.89	.346	.487

Note. Orthography was effect-coded with -0.5 for English and +0.5 for German and word length was centered. Thus, positive values for Orthography indicate larger values of the particular measure for German children. *t*-values are given for LME and *z*-values for GLME (indicated by log odds). *P*-values were computed using LRT and the R package afex (Singmann, 2015). *p*-unc. = uncorrected *p*-values and *p*-cor. = corrected *p*-values for multiple testing using the Benjamini-Hochberg method (Benjamini & Hochberg, 1995).

WORD AND SENTENCE READING IN GERMAN AND ENGLISH | 36

Table 6

Results of the LME for Local Word Processing and Global Sentence Processing Parameters for German and English Adults.

Local word-based variables	Coefficient	Estimate	*SE*	*t*-/*z*-value	χ^2	*p*-unc.	*p*-cor.
Measures of first-pass processing							
Mean first fixation duration (log)							
	Intercept	5.42	0.02	322.95	-	-	-
	Orthography	0.02	0.03	0.55	0.30	.586	.738
	Word length	0.01	<0.01	1.84	3.34	.067	.132
	Orthography × Word length	0.01	0.01	0.91	0.82	.365	.567
Mean gaze duration (log)							
	Intercept	5.54	0.02	310.26	-	-	-
	Orthography	0.04	0.04	1.19	1.40	.236	.394
	Word length	0.05	<0.01	12.00	116.89	<.001	<.001
	Orthography × Word length	0.02	0.01	3.26	10.38	.001	.004
Mean number of first-pass fixations							
	Intercept	1.03	0.02	49.15	-	-	-
	Orthography	0.16	0.04	4.02	13.61	<.001	<.001
	Word length	0.12	<0.01	25.24	334.91	<.001	<.001
	Orthography × Word length	0.00	0.01	0.55	0.30	.582	.738
First-pass refixation probability (log odds)							
	Intercept	-2.02	0.09	-23.71	-	-	-
	Orthography	0.38	0.17	2.31	5.01	.025	.060
	Word length	0.43	0.02	19.48	247.77	<.001	<.001
	Orthography × Word length	0.12	0.04	2.85	8.01	.005	.013
Skipping probability (log odds)							
	Intercept	-2.40	0.13	-18.62	-	-	-
	Orthography	-1.23	0.25	-4.86	19.07	<.001	<.001
	Word length	-0.63	0.04	-16.97	246.73	<.001	<.001
	Orthography × Word length	-0.13	0.07	-1.95	3.81	.051	.109

WORD AND SENTENCE READING IN GERMAN AND ENGLISH   37

Measures of second-pass processing Mean re-reading time (ms)						
Intercept	33.52	5.81	5.77	-	-	-
Orthography	-5.34	11.58	-0.46	0.21	.645	.753
Word length	6.88	0.85	8.05	58.29	<.001	<.001
Orthography × Word length	0.53	1.63	0.32	0.10	.747	.841
Mean number of re-reading fixations						
Intercept	0.15	0.02	5.96	-	-	-
Orthography	-0.01	0.05	-0.18	0.03	.854	.906
Word length	0.03	<0.01	10.34	89.86	<.001	<.001
Orthography × Word length	0.00	0.01	-0.27	0.07	.785	.862
Measures of total processing Mean total word reading time (log)						
Intercept	5.64	0.02	264.25	-	-	-
Orthography	0.03	0.04	0.62	0.39	.534	.728
Word length	0.06	<0.01	13.43	140.11	<.001	<.001
Orthography × Word length	0.02	0.01	2.83	7.81	.005	.014
Mean total number of fixations						
Intercept	1.17	0.04	30.33	-	-	-
Orthography	0.16	0.08	2.07	4.07	.044	.098
Word length	0.15	0.01	23.18	301.81	<.001	<.001
Orthography × Word length	0.00	0.01	0.13	0.02	.896	.906
General refixation probability (log odds)						
Intercept	-1.30	0.12	-10.77	-	-	-
Orthography	0.19	0.24	0.81	0.64	.424	.615
Word length	0.43	0.02	19.30	259.97	<.001	<.001
Orthography × Word length	0.17	0.04	3.91	15.28	<.001	<.001
Global sentence-based variables Mean fixation duration/sentence (log)						
Intercept	5.47	0.02	297.38	-	-	-

		Estimate	SE	t/z	χ²	p-unc.	p-cor.
	Orthography	0.02	0.04	0.45	0.20	.653	.753
	Word length	0.01	0.01	1.88	3.47	.063	.128
	Orthography × Word length	-0.01	0.01	-0.81	0.65	.419	.615
Total sentence reading time (log)							
	Intercept	7.70	0.03	226.73	-	-	-
	Orthography	0.09	0.07	1.39	1.89	.169	.293
	Word length	0.08	0.02	4.15	16.32	<.001	<.001
	Orthography × Word length	0.02	0.04	0.54	0.29	.590	.738
Total number of fixations/sentence							
	Intercept	9.73	0.33	29.13	-	-	-
	Orthography	0.72	0.67	1.08	1.16	.282	.453
	Word length	0.68	0.20	3.40	11.14	<.001	.003
	Orthography × Word length	0.19	0.40	0.48	0.23	.631	.753
Mean number of interword regressions/sentence							
	Intercept	0.85	0.11	7.76	-	-	-
	Orthography	-0.33	0.22	-1.50	2.19	.139	.260
	Word length	0.07	0.05	1.43	2.04	.153	.276
	Orthography × Word length	0.01	0.10	0.12	0.01	.906	.906
Mean percentage of interword regressions/sentence (log odds)							
	Intercept	0.09	0.01	9.66	-	-	-
	Orthography	-0.04	0.02	-2.46	5.56	.018	.046
	Word length	0.00	<0.01	-0.16	0.02	.874	.906
	Orthography × Word length	0.01	0.01	0.74	0.54	.460	.648

Note. Orthography was effect-coded with -0.5 for English and +0.5 for German and word length was centered. Thus, positive values for Orthography indicate larger values of the particular measure for German adults. *t*-values are given for LME and *z*-values for GLME (indicated by log odds). *P*-values were computed using LRT and the R package afex (Singmann, 2015). *p*-unc. = uncorrected *p*-values and *p*-cor. = corrected *p*-values for multiple testing using the Benjamini-Hochberg method (Benjamini & Hochberg, 1995).

Appendix

Matched Sentences

German	English
Ich hasse das Wetter im Winter es sei denn es schneit.	I hate the weather in winter except when it is snowing.
Harrys Erklärung war nicht gerade plausibel aber dafür kreativ.	Harry's explanation was not very plausible, but it was creative.
Robert ist ein typischer Pessimist, warnt mich seine Mutter.	Robert is a typical pessimist, his mother warns me.
Die Musik im Radio ist laut aber gut.	The music on the radio is loud but good.
Großvater hat ein Problem mit seinem Knie.	Grandfather has a problem with his knee.
Dies ist eine interessante Diskussion, sagt der Student.	This is an interesting discussion, says the student.
Meine Mutter trinkt nie Bier aber sie liebt Kaffee.	My mother never drinks beer but she loves coffee.
Laura ist gut im Volleyball und Marc ist gut im Tennis.	Laura is good at volleyball and Marc is good at tennis.
Das neue Hotel öffnet im Juli.	The new hotel will open in July.
Lisa spielt Oboe und ihr Bruder spielt Trompete.	Lisa plays the oboe and her brother plays the trumpet.

WORD AND SENTENCE READING IN GERMAN AND ENGLISH   40

Der junge Schimpanse lebt in einem Käfig im Zoo.   The young chimpanzee lives in a cage at the zoo.

Dennis ist aus dem Koma erwacht, sagt Doktor Müller.   Dennis has awoken from his coma, says Doctor Miller.

Kann ich eine Zigarette rauchen, fragte der Elektriker.   Can I smoke a cigarette, asks the electrician.

Der große Pianist gab ein Konzert in Rom.   The great pianist gave a concert in Rome.

Die Nadel von Toms Kompass ist zerbrochen.   The needle of Tom's compass is broken.

Sechzig Sekunden sind eine Minute, sagt Tina.   There are sixty seconds in a minute, says Tina.

Produkte guter Qualität haben oft einen hohen Preis.   Products of good quality often have a higher price.

Paula aß eine Blaubeere und Kim einen Apfel.   Paula ate a blueberry and Kim ate an apple.

Die Äpfel in der Box sind rot und grün.   The apples in the box are red and green.

Die Trompete ist das lauteste Instrument im Orchester.   The trumpet is the loudest instrument in an orchestra.

Sarahs neuer Bikini ist blau und pink.   Sarah's new bikini is blue and pink.

Nachts sehen wir den Mond und die Sterne.   At night, we see the moon and the stars.

Der Salamander isst Würmer und Insekten.   The salamander eats worms and insects.

WORD AND SENTENCE READING IN GERMAN AND ENGLISH   41

Onkel Thomas hat eine Kuh und drei Hennen.	Uncle Thomas has a cow and three hens.
Der neue Minister spricht sehr laut im Parlament.	The new minister speaks very loudly in parliament.
Bienen machen aus Nektar Honig, sagt Peter.	Bees make honey from nectar, says Peter.
Der Angler fing einen Aal und drei Krabben.	The angler caught an eel and three crabs.
Hast du den Piep gehört, fragte Julia.	Have you heard the beep, asked Julia.
Vater reparierte die Maschine letztes Wochenende.	Father repaired the machine last weekend.
Kevin aß eine Mango im Park.	Kevin ate a mango in the park.
Dies ist eine komplett neue Situation, sagte der Präsident.	This is a completely new situation, said the president.
Patrick geht auf Safari nach Afrika.	Patrick is going on a safari in Africa.
Dein Bruder ist ein Optimist, sagt Martin.	Your brother is an optimist, says Martin.
Der Priester aß vier Tomaten.	The priest ate four tomatoes.
David isst eine Kiwi und zwei Bananen.	David is eating a kiwi and two bananas.
Die Gazelle lebt in Afrika.	The gazelle lives in Africa.

WORD AND SENTENCE READING IN GERMAN AND ENGLISH   42

German	English
Das Wetter im Februar ist nicht so gut wie das im Juni.	The weather in February is not as good as it is in June.
Eric trinkt Tee und Susi trinkt Milch.	Eric drinks tea and Suzie drinks milk.
Der Dieb stahl Vaters Axt und seinen Hammer.	The thief stole father's axe and his hammer.
Der Bischof hat ein Aquarium daheim.	The bishop has an aquarium at home.
Onkel Thomas sitzt im Kajak mit dem Paddel in der Hand.	Uncle Thomas sits in the kayak with the paddle in his hands.
Der Monat September folgt auf den Monat August.	The month of September follows the month of August.
Simon ist sieben Jahre alt.	Simon is seven years old.
Mein Vater liebt Fußball und meine Mutter liebt Golf.	My father loves football and my mother loves golf.
Dieser Kaffee hat ein gutes Aroma, sagt Tanja.	This coffee has a good aroma, says Tanya.
Der junge Flamingo hat graue Federn.	The young flamingo has grey feathers.
Kann ich in der Mitte sitzen, fragt Nora.	Can I sit in the middle, asked Nora.
Der alte Professor vergaß seine Notizen.	The old professor forgot his notes.