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Children's and adults' parafoveal processes in German: Phonological and orthographic effects

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Phonological and orthographic information has been shown to play an important role in parafoveal processing in skilled adult reading in English. In the present study, we investigated whether similar parafoveal effects can be found in children using the boundary eye tracking method. Children and adults read sentences in German with embedded target nouns which were presented in original, pseudohomophone (PsH), transposed-letter (TL), lower-case and control conditions to assess phonological and orthographic preview effects. We found evidence of PsH preview benefit effects for children. We also found TL preview benefit effects for adults, while children only showed these effects under specific conditions. Results are consistent with the developmental view that reading initially depends on phonological processes and that orthographic processes become increasingly important.

Keywords: Eye tracking; Parafoveal processing; Pseudohomophones; Reading; Transposed-letters.

Reading requires the processing of words on many different levels of representation. Skilled readers derive the orthographic codes of printed words, decode their corresponding phonological codes, and use these to retrieve lexical and semantic information stored in the mental lexicon. In connected text, readers are presented with simultaneous information of multiple words and their semantic and syntactic relationships. Many studies have shown that skilled readers are able to extract information not only from words being directly focused on but also from upcoming letters and words in a text (parafoveal processing, see Hyönä, 2011; Rayner, 1998; Schotter, Angele, & Rayner, 2012, for reviews). Efficient parafoveal processes may represent key determinants of fluent reading of continuous text. However, what remains largely unclear is whether beginning readers are able to use parafoveal information and how parafoveal processes develop as reading skill advances. There is good reason to believe, based on current models of visual word recognition and empirical evidence in transparent orthographies, that children may initially be more dependent on phonological codes than adults while orthographic codes become increasingly important for efficient word identification (Ziegler, Bertrand, Lété, & Grainger, 2013). The evidence of this developmental pattern in parafoveal processes is as yet lacking. It is also unclear whether phonological and orthographic preview effects found in orthographically opaque languages such as English and French generalise to more transparent orthographies such as German in which phonological decoding is less of a challenge (Ziegler et al., 2010).

In the present study, we address the question of whether beginning readers in German are able to

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use phonological and orthographic information of upcoming words to facilitate word recognition processes. In the following sections, we will cover some of the current findings on parafoveal processing using eye tracking methods. We will then present data from a reading experiment with both skilled adult readers and children using the boundary method. Two sets of sentences with manipulated parafoveal previews of embedded target words were presented to assess parafoveal processing of phonological and orthographic information, respectively.

Parafoveal processes in adult readers

During the reading of connected text, the eyes move in a series of jumps (saccades) of 7–10 letter spaces, which bring parts of the text into focus. Printed information is then processed during resting periods (fixations) which last an average 200–250 ms. Information encoded in a word is most efficiently extracted when a reader brings the word into the central 2° of their visual field, the fovea, where visual acuity is highest (Rayner & Bertera, 1979). However, although foveal decoding processes are more efficient, skilled readers are also able to use limited information derived from the parafovea which extends up to 5° to the right of the fovea (Rayner, 1998). While the visual acuity of the parafovea decreases with distance to the central field of vision, many studies have shown that having valid information available in the parafovea facilitates word recognition processes when a reader's eyes subsequently move to the next word in a text. There is substantial evidence for English that skilled readers can detect abstract orthographic codes as well as phonological codes and use these to activate lexical representations, facilitating later foveal word recognition processes (Hyönä, 2011; Rayner, 1975; Schotter et al., 2012), although there is still some debate about whether semantic and morphological information can be derived from the parafovea (Dimigen, Kliegl, & Sommer, 2012; Häikiö, Bertram, & Hyönä, 2010; Hohenstein & Kliegl, 2013a; Schotter, 2013).

Since the availability of eye tracking methods there have been extensive studies of parafoveal processes in reading (Rayner, 1998). These have established an evidence base for parafoveal processing of phonological (Ashby & Rayner, 2004; Ashby, Treiman, Kessler, & Rayner, 2006; Dare & Shillcock, 2013; Miellet & Sparrow, 2004; Pollatsek, Lesch, Morris, & Rayner, 1992; Sparrow & Miellet, 2002) and orthographic information (Balota, Pollatsek, & Rayner, 1985; Inhoff, 1989; Rayner, 1975; Johnson, Perea, & Rayner, 2007; White, Johnson, Liversedge, & Rayner, 2008). A large amount of this evidence stems from experiments using the gaze-contingent boundary paradigm (Rayner, 1975). In this paradigm, sentences are presented as a single line of text with embedded target words while readers' eye movements are tracked. The target words are initially presented as previews, which can either be identical to the target word or manipulated by substituting letters to alter word form, phonology, meaning, etc. As soon as a reader's eyes move across an invisible boundary directly in front of the space preceding the preview, the preview is exchanged with the target word. The preview is assumed to be processed in the parafovea before the boundary is crossed, beginning the activation of associated lexical entries. The degree to which the preview and target share phonological and orthographic codes determines the facilitation of subsequent foveal word recognition processes. Faster word identification of targets with related previews than unrelated previews is interpreted as a preview benefit (Schotter et al., 2012).

Phonological effects

A number of different manipulations have been used to investigate phonological processes in the parafovea using the boundary method. Rayner, McConkie, and Zola (1980) compared fixation durations on a target word (e.g., plane) following either a preview with an identical initial phoneme (e.g., prune) or dissimilar initial phoneme (phone). No differences were found between preview conditions, leading to the conclusion that phonological codes were not processed in the parafovea. However, the generalisability of these results has been questioned, as initial phoneme overlap may not be sufficient to produce a phonological preview benefit (Pollatsek et al., 1992). A different approach was used by Pollatsek et al. (1992) who used homophones as target previews to provide a higher degree of phonological overlap between preview and target. Homophones represent orthographically and semantically dissimilar but phonologically identical words (e.g., genes, jeans). Although the effects were not large, Pollatsek et al. (1992) found that homophones resulted in a greater preview benefit than non-homophonic control (CTL) words which were matched on visual similarity to the target with the homophones (e.g., genes–germs, jeans–prose). However, in a similar study using homophone previews, Chace, Rayner, and Well (2005) found that only skilled adult readers showed evidence of a phonological preview benefit while poor readers did not. Further evidence for phonological preview benefit effects in French is provided by Miellet and Sparrow (2004) using pseudohomophone (PsH) previews. PsHs are non-words which share the phonology but not the orthography of target words (e.g., rain–rane). They found that PsH previews resulted in shorter fixation durations on the target word than non-homophone non-word previews. Ashby et al. (2006) also found that, for English, target words (e.g., chirp) are identified faster following non-word previews which share phonologically similar internal vowel phonemes (e.g., cherg) than dissimilar internal vowel phonemes (chorg). Although the studies mentioned here use differing types of phonological previews, the evidence does suggest that phonological preview benefits exist in English and French for skilled adult readers. These effects are in line with the consistent evidence for a strong impact of phonological information in reading in English (Rastle & Brysbaert, 2006). Whether these effects generalise to more transparent orthographies, such as German, is not clear.

Orthographic effects

Johnson et al. (2007) conducted a series of three experiments in which sentences were presented with a target word (e.g., mustard) following previews which were manipulated by transposing adjacent letters in initial (e.g., umstard), internal (e.g., musatrd) or final (e.g., mustadr) positions while preserving letter identities of the target word. Fixation durations on target words following transposed letter (TL) previews were compared with fixation durations following CTL previews in which TLs were substituted with letters unrelated to the target word. Their results provided evidence of TL preview benefit effects for five- and seven-letter words in silent sentence reading and that the TL effects were evident up to five letters into a word (earlier studies suggested TL effects up to three letters into a word, see Rayner, Well, Pollatsek, & Bertera, 1982). This indicates that letter identity (ID) codes can be extracted from the parafovea with a degree of independence from absolute letter position.

Parafoveal processes thus appear to use approximate letter position codes rather than fixed letter strings (Andrews, 1996; Peressotti & Grainger, 1999). However, Johnson et al. (2007) found weaker TL effects for initial and final letters, suggesting that the absolute position of external letters plays a special role in word identification, which has also been found in foveal word recognition tasks (Friedmann & Gvion, 2001; Humphreys, Evett, & Quinlan, 1990). Stronger disruption of word identification processes has also been found for initial TL previews than internal TL previews (see White et al., 2008, for a review of how this effect relates to different word recognition models). The converging evidence suggests that the ID and position of external letters and particularly the initial letters of a word have special importance in word recognition. These findings mirror TL effects found in masked priming experiments and mega-studies (Adelman et al., 2014; Perea & Lupker, 2003). However, there are currently no studies showing evidence of TL preview benefit effects in transparent orthographies such as German.

We made use of a further special characteristic of the German writing system to investigate the importance of the initial letter of words. The German script places particular importance on the initial letter of nouns by distinguishing them with a capital letter. The capitalisation of nouns functions as a cue for the lexical class of the word and theoretically provides a shortcut for lexical access. However, although studies have shown facilitating effects of noun capitalisation for reading speed (Bock, 1989), recent boundary method experiments have not found a preview benefit effect for the capitalisation of nouns in German-speaking adults (Hohenstein & Kliegl, 2013a, 2013b). Hohenstein and Kliegl (2013a) argue that the lack of a capitalisation preview benefit effect was due to the young adults in their study having high exposure to text forms (e.g., text messages, web pages, etc.) which do not consistently use capitalisation rules. Children, on the other hand, may make more use of noun capitalisation cues as they are an explicit element of German reading education.

Development of phonological and orthographic processes

There are clear differences in the eye movements of children and adults during reading. Children generally make shorter saccades, more and longer fixations, more regressive saccades, and skip fewer words than adults (Rayner, 1998). Eye tracking studies have also shown that the visual span, i.e., the number of letter spaces from which a reader is able to derive information from the visual field, differs both as a function of age and of reading skill (Häikiö, Bertram, Hyönä, & Niemi, 2009; Rayner, 1986). These studies have generally shown that the pattern of eye movements undergoes a developmental change as reading skill increases and that there are large individual differences. The differences in eye movement behaviour between children and adults are generally assumed to be due to the efficiency of lexical processes rather due to the development of ocular-motor skills (Blythe & Joseph, 2011; Huestegge, Radach, Corbic, & Huestegge, 2009; Reichle et al., 2013).

There is thus extensive evidence for quantitative changes in eye movement behaviour in reading development. Less is known about the nature of parafoveal processing in children and what kinds of information are extracted from the parafovea. There is, however, some evidence that children use certain kinds of parafoveal information. For instance, Finnish children have been shown to draw greater preview benefit from the second constituent in compound nouns than from adjective noun phrases (Häikiö et al., 2010). Phonological and orthographic processes are generally accepted to play a key role in reading development (Ehri, 1992; Frith, 1985; Goswami, Ziegler, Dalton, & Schneider, 2001; Grainger, Lété, Bertand, Dufau, & Ziegler, 2012; Grainger & Ziegler, 2011; Share, 1995; Ziegler & Goswami, 2005; Ziegler et al., 2013). It is very likely that both phonological and orthographic information plays an important role in parafoveal processing in children. It is also likely that these processes show developmental trends, which can be directly related to current models of word processing.

Dual route models of visual word recognition (e.g., CDP, Perry, Ziegler, & Zorzi, 2007; Zorzi, 2010; DRC, Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) essentially differentiate between two main processing routes. The sublexical route represents the serial decoding of a string of graphemes to their corresponding phonemes, while the lexical route represents direct access to whole word orthographic representations and semantic associations. There have been successful attempts to simulate the process of building an orthographic mental lexicon through repeated successful phonological decoding using the CDP model (Ziegler, Perry, & Zorzi, 2014), supporting the basic assumption that the dual route system undergoes developmental change. In line with the evidence from PsH and TL masked priming studies, dual route models assume a qualitative shift from sublexical, phonological processing to a more global orthographic, lexical-processing route. Grainger et al. (2012) predicted and were able to show a trend of decreasing PsH priming effects from school years one to five and across reading age. In contrast, they found stable TL priming effects, supporting the hypothesis that phonological codes are initially of most importance, but progressively give way to orthographic codes which facilitate more efficient word identification. Given these trends in single word recognition processes, it is plausible that the developmental pattern of PsH and TL effects found in masked priming experiments may also be found in parafoveal processes, which are a hallmark of efficient reading in skilled adult readers. Indeed, a recent review of neurophysiological eye movement studies argues that the efficient control of eye movements during reading necessarily requires a substantial amount of parafoveal lexical processing (Reichle & Reingold, 2013).

The present study

In the present study, children and adults read sentences with embedded target words which were presented as manipulated previews using the boundary eye tracking method. Two sets of sentences were used containing either PsH or TL and capitalisation preview manipulations together with their corresponding CTL conditions. Different sentence stimuli were used in each set and both sets were intermixed and presented in random order. Based on current models of visual word identification, we hypothesised that children would show stronger evidence of PsH preview benefit than adults, while adults should show TL preview benefits. Preview benefits of noun capitalisation were not expected for adults, as other studies have not found these effects. However, as children may profit to a greater extent from the facilitation through the lexical class cue of noun capitalisation, we predicted a capitalisation preview benefit for children.

METHOD

Participants

The sample consisted of 24 primary school children (age: M = 8.46, SD = 0.59) and 24 adults (age: M = 23.92, SD = 2.28), recruited using the participant database of the Max Planck Institute for Human Development, Berlin. All participants were native German speakers, had normal or corrected vision and had no record of reading disability. Adults and children had standard word and non-word reading scores on the Salzburger Leserechtschreibtest (SLRT-II, Moll & Landerl, 2010) which did not fall below the 10th percentile on more than one subscale. One adult and one child did not perform significantly above chance level on the sentence comprehension questions, answering less than 16 out of 24 questions correctly and were excluded from further analyses. The effective sample was therefore N = 46. Adult participants were compensated with €10 and children received €5 and a small gift.

Materials

Pseudohomophone targets

Forty-two target words were selected (see Table A1 in the Appendix) with an average word length of 4.61 letters (SD = 0.76) and an average log10 lemma frequency of 1.30 (SD = 0.64) in the German childLex corpus (Schroeder, Würzner, Heister, Geyken, & Kliegl, 2014). All target words were capitalised nouns. For each target word, three preview conditions were generated: ID, PsH and CTL. PsHs were created by exchanging a single vowel letter to manipulate the spelling, while preserving the phonology and length of the preview (e.g., Blech—Bläch, engl. tray). CTLs were created by substituting the vowels manipulated in the PsH condition to change both spelling and phonology of the preview, while preserving word length (e.g., Bläch—Blüch). Bigram frequencies and orthographic neighbourhood sizes were calculated using the childLex database to test for differences between PsH and CTL condition previews.

An analysis of variance (ANOVA) using log transformed type bigram frequency as dependent variable found that the PsH and CTL preview conditions were identical (p = .821), but also that both had lower bigram frequencies than the ID condition, $F(2, 123) = 5.79$, p = .004. Similarly, an ANOVA using orthographic neighbourhood size as dependent variable again found that PsH and CTL condition previews were identical (p = .280) and that both had smaller neighbourhood sizes than the ID condition, $F(2, 123) = 11.08$, $p < .001$. The analyses thus demonstrate that any differences in preview benefit effects found between PsH and CTL conditions (see Table 1) were not due to differing linguistic properties between preview conditions.

TL targets

Sixty target words were selected (see Table A2 in the Appendix), of which 30 were four and 30 were five letters long with an average log10 lemma frequency of 1.57 (SD = 0.32) in the German

TABLE 1
Mean lexical characteristics of phonological and orthographic previews with standard deviations

	Length (letters)	*Frequency (lemma, log10)*	*Neighbors (Coltheart N)*	*Bigram frequency (type, log10)*
Phonological previews				
Identity	4.61 (0.76)	1.30 (0.64)	6.24 (4.65)	22.49 (3.39)
Pseudohomophone			3.98 (2.75)	20.64 (3.43)
Control			2.86 (2.13)	20.25 (3.53)
Orthographic previews				
Identity	4.5 (0.50)	1.57 (0.32)	5.60 (4.07)	20.69 (2.46)
Lower case			5.83 (4.17)	20.90 (2.18)
Initial position				
Transposed letter			0.50 (2.54)	19.72 (2.54)
Control			0.63 (2.33)	18.79 (2.33)
Internal position				
Transposed letter			2.58 (2.39)	20.18 (2.39)
Control			1.27 (2.32)	19.69 (2.32)

childLex corpus. All target words were capitalised nouns. For each target word, five additional manipulated preview conditions were generated. In the lower-case (LC) condition, the initial capital letter was replaced with an LC initial letter (e.g., Rand—rand, engl. edge). In the initial position TL condition (TL-initial), the first and second letters of the target were exchanged, where the initial letter was capitalised (e.g., Rand—Arnd) and the corresponding CTLs were created by substituting the TLs (e.g., Arnd—Ucnd). Similarly, in the internal position TL condition (TL-internal), the second and third letters were exchanged (e.g., Rand—Rnad, engl. edge) and the corresponding CTLs were again created by substituting the exchanged letters (e.g., Rnad—Rcod). In the CTL conditions ascenders were substituted by ascenders, descenders with descenders, vowels with vowels, consonants with consonants and capitals with capitals. The childLex database was again used to compare log transformed bigram frequencies and neighbourhood size between the ID and five manipulated preview conditions. ANOVAs using type bigram frequency as dependent variable found that ID and LC conditions did not differ (p = .739), and that TL-initial and CTL-initial conditions (p = .874), as well as TL-internal and CTL-internal conditions (p = .994) were identical. Bigram frequencies were lower for TL and CTL conditions than ID and LC conditions, F (5, 354) = 6.486, p < .001. Similarly, ANOVAs with orthographic neighbourhood size as dependent variable found that ID and LC conditions were identical (p = .999), as were TL-initial and CTL-initial conditions (p = .143) and TL-internal and CTL-internal conditions (p = .998). The analyses again show that any differences in preview benefit effects found between TL and CTL conditions and LC and ID conditions (see Table 1) were not due to differing linguistic properties of the previews.

Stimulus sentences

Target words were embedded in sentences written to be engaging for primary school children with themes based on pirates, fantasy, family, etc. Sentences were 7–9 words long (M = 8.05, SD = 0.62) and targets words were positioned at 5th or 6th position. Each sentence was displayed on a single line of text and the target words were preceded by adjectives with an average length of 6.78 letters (SD = 1.11) and average log10 lemma frequency of 2.07 (SD = 0.67) in the childLex corpus.

Apparatus

An EyeLink 1000 eyetracker (SR Research, Ontario, Canada) was used to record eye movements during reading at a rate of 1,000 Hz and spatial resolution of 0.01°. Stimuli sentences were presented on a 21″ ASUS LCD monitor, with a refresh rate of 120 Hz and resolution of 1,024 × 768 pixels. Participants sat at a viewing distance of 65cm with an assisting head and chin rest to reduce head movements. Sentences were presented in Courier New font in white, size 14 (corresponding to 0.35 degrees of visual angle per letter), on a black background using the UMass Eye Track 7.10m software (Stracuzzi & Kinsey, 2006). An invisible boundary was positioned directly behind the last letter of the adjective preceding the target word. Target previews were displayed until the boundary was crossed by a saccade, at which point the preview was exchanged with the target word. Participants were debriefed post-experiment that they had read sentences with spelling errors. Participants were generally unaware of the spelling errors, except in the case of display change errors (<2% trials). These trials were excluded from further analyses in the data cleaning procedure.

Procedure

A nine dot calibration of the eyetracker was conducted and validated with each participant until a calibration accuracy of at least 0.5 was achieved. Four practice sentences were each followed by a yes–no comprehension question, to which participants had to respond to on a gamepad. Incorrect answers to the comprehension questions during the practice trials were corrected. Sentences from the phonological manipulation and orthographic manipulation experiments were intermixed and presented in randomised order. Participants read all 102 sentences with three shorts breaks. The eyetracker was recalibrated after the practice trials as well as after each break and as necessary when x or y-axis drift was detected. Reading was binocular while the right eye was tracked. Each sentence was preceded by a fixation cross which triggered the stimulus sentence on fixation and participants ended the trial by pressing a button on a gamepad. Twenty-four of the sentences were followed by a forced-choice comprehension question to which participants responded yes or no with buttons on the gamepad.

The two sets of 42 sentences containing PsH manipulations and 60 sentences containing TL and LC manipulations were intermixed and presented in random order. At the end of the test session, each participant then completed the SLRT-II reading test on a laptop.

Analysis

The eye movement data were cleaned in two steps. First, all trials were deleted if the display change failed to trigger, the display change did not occur during the saccade preceding the first fixation on a target, or if a blink occurred on the target word or directly preceding the first fixation of the target. Trials were also deleted if the saccade crossing the boundary was not initiated from the word directly preceding the target word. This criteria was chosen as it is uncertain if parafoveal information is derived from further than one word to the right of the current fixation (Angele & Rayner, 2011; Angele, Slattery, Yang, Kliegl, & Rayner, 2008; Kliegl, Risse, & Laubrock, 2007). In this step, 15.05% of trials were excluded on average for children and 9.39% of trials on average for adults. Fixations of less than 80 ms were combined with an adjacent fixation if this was within one character. Shorter fixations of 40 ms or less were deleted if within three characters of the nearest fixation. Due to a technical error, one CTL preview was presented incorrectly and the target, PsH and CTL conditions for the affected target word were excluded from the analysis. In 5.27% of the remaining trials children skipped the target word while adults skipped an average 6.68% of the targets. Skipped trials were not included in the analyses. In the second step, fixations were deleted for each participant if their duration was 2.5 standard deviations above the mean for each eye movement measure. For this procedure, eye movement data were cleaned separately for children and adults and then combined to a single data-set for all following analyses. Four eye movement measures were calculated (Rayner, 2009), including *single fixation duration* (cases where only a single fixation is made on a target), *first fixation duration* (the only fixation or the first of multiple fixations on a target), *gaze duration* (all fixations on a target before the first saccade leaves the target) and *go-past time* (all fixations starting with the first fixation on a target to the first saccade to the right of the target). Less than 2% of fixations were deleted for children and adults in each dependent measure.

Linear-mixed models (lme) were used to analyse the eye movement data for each dependent measure in the R environment (R Development Core Team, 2012) with the lme4 package version 1.17 (Bates, Maechler, & Bolker, 2012). Participants and items were treated as crossed random effects and all fixation duration measures were log transformed. Age group (child or adult) was included as a between-subjects factor and preview condition as a within-subjects factor. Means and standard errors for each age group, condition and contrast were estimated using cell-mean coding. Contrasts between preview conditions were estimated using the multicomp package function glth (Hothorn, Bretz, & Westfall, 2008). For the PsH preview benefit analyses two contrasts estimated the preview benefit of the ID over the PsH condition (PsH—ID) and the preview benefit of the PsH over the CTL condition (CTL—PsH). For the TL preview benefit analysis, five contrasts were calculated to estimate the preview benefit of ID over LC (LC—ID), the preview benefit of ID over TL in initial position (TL-initial—ID) and internal position (TL-internal—ID), as well as the TL preview benefit of TL over CTL in initial position (CTL-initial—TL-initial) and internal position (CTL-internal—TL-internal).

RESULTS

Global measures

Children and adults did not differ in their normalised score on the combined scales of the SLRT-II standardised reading test or on their comprehension scores ($|ts| < 2$), indicating that both groups had age appropriate reading behaviour. The global eye movement measures displayed in Table 2 show a typical developmental pattern for children and adults (Rayner, 1998). Children took significantly longer to read the stimuli sentences than adults ($|t| > 2$). Longer reading times appear to be the product of children making significantly more fixations and also making significantly longer fixations than adults ($|ts| > 2$). Children and adults did not differ significantly in saccade length ($|t| < 2$).

TABLE 2
Global measures of mean (standard error) age, gender, standardised reading ability, sentence comprehension and eye movements of the child and adult participant groups

Measure	*Children*	*Adults*
N	23	23
Gender (female)	12	15
Age (years)	8.46 (0.12)	23.78 (0.47)
Standardised reading measures		
Word reading (raw)	74.22 (3.48)	118.28 (3.71)
Non-word reading (raw)	44.83 (2.26)	81.57 (3.19)
Word reading (percentile)	56.84 (4.87)	46.45 (6.45)
Non-word reading (percentile)	57.89 (5.34)	60.38 (5.61)
Reading task measures		
Sentence comprehension (% correct)	90 (2)	93 (1)
Total sentence reading time (ms)	4,930 (285)	3,212 (154)
Fixations per sentence (*N*)	13 (0.7)	9 (0.3)
Fixation duration average per sentence (ms)	272 (4.4)	243 (3.4)

Target measures

The dependent eye tracking measures are summarised in Tables 3 and 4, including back-transformed average fixation durations and standard errors derived from the model estimates, contrasts between preview conditions and the interactions between the contrasts and age group. In the following sections, we present the effects of parafoveal PsH, capitalisation and TL previews on target word identification. The effects are presented for each dependent eye movement measure for children, adults and their interactions.

Pseudohomophone effects

In single fixation duration, there was a significant PsH benefit effect of 28 ms for children, $b = -0.09$, $SE = 0.03$, $t = -3.08$, $p = .002$. We did not, however, find a PsH preview benefit for adults, $b = -0.01$, $SE = 0.03$, $t = -0.50$, $p = .616$, and the significant interaction between the PsH preview benefit effect and age group, $b = -0.08$, $SE = 0.04$, $t = -2.00$, $p = .045$, shows that the preview effect differed between children and adults. Children's single fixation durations did not differ between PsH and ID conditions, $b = -0.05$, $SE = 0.03$, $t = -1.79$, $p = .073$, but single fixations were significantly longer in the PsH condition for adults, $b = -0.05$, $SE = 0.03$, $t = -2.00$, $p = .045$. In first fixation duration, we found no significant PsH benefit effect for children, $b = -0.04$, $SE = 0.03$, $t = -0.16$, $p = .110$, or adults, $b = 0.02$, $SE = 0.03$, $t = 0.63$, $p = .529$, and there was no interaction between the PsH preview benefit effect and age group, $b = -0.06$, $SE = 0.04$, $t = -1.57$, $p = .116$. First fixation durations were longer in the PsH than ID condition for children, $b = -0.05$, $SE = 0.03$, $t = -2.01$, $p = .045$, and adults, $b = -0.05$, $SE = 0.03$, $t = -1.98$, $p = .048$. Similar to the single fixation measure, a significant PsH benefit effect of 34 ms was found in gaze duration for children, $b = -0.10$, $SE = 0.03$, $t = -3.54$, $p < .001$, and no

TABLE 3
Phonological preview effects: mean fixation durations (in milliseconds) and standard errors of four dependent measures for children and adults in three preview conditions

	Single fixation	*First fixation*	*Gaze duration*	*Go-past time*
Children				
Identity	274 (11)	257 (9)	303 (13)	386 (25)
Pseudohomophone	289 (11)	271 (10)	317 (14)	405 (25)
Control	317 (13)	283 (10)	351 (15)	434 (27)
Identity—pseudohomophone (Δ)	15	14*	14	19
Identity—pseudohomophone (Δ)	43***	26***	48***	48**
Control—pseudohomophone (Δ)	28**	12	34***	29
Adults				
Identity	215 (8)	212 (7)	221 (10)	236 (13)
Pseudohomophone	226 (9)	223 (8)	236 (10)	260 (14)
Control	229 (9)	219 (8)	234 (10)	265 (15)
Identity—pseudohomophone (Δ)	11*	12*	15*	25**
Identity—control (Δ)	14*	8	13**	30**
Control—pseudohomophone (Δ)	3	–4	–2	5

$^*p < .05$, $^{**}p < .01$, $^{***}p < .001$. The control—pseudohomophone (Δ) differences represent the PsH preview benefit effect.

TABLE 4
Orthographic preview effects: mean fixation durations (in milliseconds) and standard errors of four dependent measures for children and adults in six preview conditions

	Single fixation	*First fixation*	*Gaze duration*	*Go-past time*
Children				
Identity	259 (10)	253 (9)	285 (12)	316 (15)
Lower case	299 (12)	278 (10)	323 (14)	349 (17)
Lower case—identity (Δ)	40***	25***	38***	32*
Initial position				
Transposed letter	308 (13)	284 (10)	352 (15)	388 (19)
Control	331 (11)	300 (10)	357 (14)	397 (17)
Transposed letter—identity (Δ)	49***	31*	67***	72***
Transposed letter—control (Δ)	23*	17	5	9
Internal position				
Transposed letter	278 (13)	272 (11)	312 (15)	349 (19)
Control	307 (12)	278 (10)	329 (14)	362 (18)
Transposed letter—identity (Δ)	19*	19*	27*	32*
Transposed letter—control (Δ)	29***	6	17	13
Adults				
Identity	210 (8)	208 (7)	217 (9)	223 (11)
Lower case	221 (9)	215 (8)	227 (10)	235 (12)
Lower case—identity (Δ)	11	6	10	12
Initial position				
Transposed letter	227 (9)	219 (8)	232 (9)	238
Control	237 (8)	227 (7)	244 (10)	254
Transposed letter—identity (Δ)	17*	11	15	15
Transposed letter—control (Δ)	10	8	12	16
Internal position				
Transposed letter	207 (9)	205 (8)	213 (10)	221 (12)
Control	228 (9)	222 (8)	229 (10)	234 (11)
Transposed letter—identity (Δ)	–2	–3	–4	–2
Transposed letter—control (Δ)	20*	17*	16*	13

*$p < .05$, **$p < .01$, ***$p < .001$. The transposed letter—identity (Δ) difference represents the TL preview benefit effect.

PsH preview benefit for adults, $b = 0.01$, $SE = 0.03$, $t = 0.29$, $p = .775$. The interaction between the PsH preview benefit effect and age group, $b = –0.11$, $SE = 0.04$, $t = –2.69$, $p = .007$, was also significant. Again, there was no significant difference in gaze duration between PsH and ID conditions for children, $b = –0.05$, $SE = 0.03$, $t = –1.57$, $p = .116$, but gaze durations were longer in the PsH condition for adults, $b = –0.06$, $SE = 0.03$, $t = –2.22$, $p = .27$. Finally, in go-past time the PsH benefit effect of 29 ms did not reach significance for children, $b = –0.07$, $SE = .04$, $t = –1.69$, $p = .092$, there was no PsH preview benefit for adults, $b = –0.02$, $SE = 0.04$, $t = –0.46$, $p = .648$, and there was no interaction between the PsH preview benefit effect and age group, $b = –0.05$, $SE = 0.06$, $t = –0.86$, $p = .387$. Go-past time was not significantly different in PsH and ID conditions for children, $b = –0.05$, $SE = 0.04$, $t = –1.21$, $p = .225$, but longer in the PsH than ID condition for adults, $b = –0.10$, $SE = 0.04$, $t = –2.48$, $p = .013$.

The results show a very clear pattern of effects. Children displayed large PsH preview benefits in single fixation and gaze duration measures while adults did not show any preview benefit from PsH over CTL previews. PsH previews did not significantly increase fixation durations compared to ID previews for children in the eye movement measures of single fixation, gaze duration or go-past time. However, adults had longer fixation durations in all dependent measures for PsH previews compared to ID previews. These findings show that children profited from the availability of phonological information in the parafovea to facilitate word recognition, while the more skilled adult readers did not.

Orthographic effects

Capitalisation effects. In single fixation duration children showed a significant 40 ms preview benefit effect of capitalisation with longer single fixation durations in the LC than ID condition, $b = –0.14$, *SE* = 0.03, *t* = –4.47, *p* < .001. For adults, however, there was no significant difference between LC and ID conditions, *b* = –0.05, *SE* = 0.03, *t* = –1.77, *p* = .08, and the significant interaction between the capitalisation preview benefit effect and age, *b* = –0.09, *SE* = 0.04, *t* = –2.17, *p* = .03, indicates that children profited from noun capitalisation while adults did not. In first fixation duration children also showed a significant 25 ms preview benefit effect of capitalisation, *b* = –0.9, *SE* = 0.03, *t* = –3.11, *p* < .001, while for adults, again, there was no significant difference between LC and ID conditions, *b* = –0.03, *SE* = 0.03, *t* = –1.01, *p* = .31. Unlike for single fixation duration, however, there was no significant interaction between the preview benefit of ID over LC, *b* = –0.06, *SE* = 0.04, *t* = –1.49, *p* = .14. In gaze duration, children showed a significant 38 ms preview benefit effect of capitalisation, *b* = –0.12, *SE* = 0.03, *t* = –3.70, *p* < .001, whereas adults did not, *b* = –0.05, *SE* = 0.03, *t* = –1.34, *p* = .18, although the interaction between the preview benefit of capitalisation and age, *b* = 0.08, *SE* = 0.05, *t* = –1.67, *p* = .10, was not significant. Finally, in go-past time children showed a significant 32 ms preview benefit effect of capitalisation, *b* = –0.10, *SE* = 0.04, *t* = –2.71, *p* = .01. For adults, there was no significant capitalisation preview benefit, *b* = –0.05, *SE* = 0.03, *t* = –1.46, *p* = .14, and there was again no significant interaction of the capitalisation preview benefit and age group, *b* = –0.04, *SE* = 0.05, *t* = –0.88, *p* = .38.

The pattern of effects for the capitalisation preview manipulation was also very clear. Children had a greater preview benefit from capitalised than non-capitalised previews while adults showed similar preview benefit from capitalised and non-capitalised noun previews.

Initial TL effects. In single fixation duration, there was a significant TL preview benefit effect of 23 ms with longer single fixation durations for children in CTL-initial than TL-initial conditions, *b* = –0.07, *SE* = 0.03, *t* = –2. 06, *p* = .04. For adults, however, we did not find a similar TL preview benefit effect in initial position, *b* = –0.04, *SE* = 0.03, *t* = –1.47, *p* = .14, and there was no significant interaction between the TL preview benefit effects at initial position with age group, *b* = –0.03, *SE* = 0.04, *t* = –0.64, *p* = .52. Single fixations were longer in the TL initial position condition than in the ID condition for both children, *b* = –0.17, *SE* = 0.03, *t* = –5.15, *p* = .01, and adults, *b* = –0.08, *SE* = 0.03, *t* = –2.76, *p* = .01. For first fixation duration, the TL preview benefit effect for children did not reach significance, *b* = –0.06, *SE* = 0.03, *t* = –1.89, *p* < .06, and there was no effect for adults, *b* = –0.03, *SE* = 0.03, *t* = –1.15, *p* = .25. First fixation durations were longer in the TL-initial position than in the ID condition for children, *b* = –0.12, *SE* = 0.03, *t* = –3.79, *p* < .001, but not for adults, *b* = –0.05, *SE* = 0.03, *t* = –1.73, *p* = .08. A similar pattern was found for gaze duration, where there was no significant TL preview benefit effect for children, *b* = –0.01, *SE* = 0.03, *t* = –0.41, *p* = .68, as well as no TL preview benefit effect for adults, *b* = –0.05, *SE* = 0.03, *t* = –1.54, *p* = .12. While children showed longer gaze durations in the TL than ID condition, *b* = –0.21, *SE* = 0.03, *t* = –6.23, *p* < .001, adults did not, *b* = –0.06, *SE* = 0.03, *t* = –1.95, *p* = .05. Finally, children did not show significant TL preview benefit effect for go-past time, *b* = –0.02, *SE* = 0.04, *t* = –0.63, *p* = .53, and there was also no TL preview benefit effect for adults, *b* = –0.06, *SE* = 0.03, *t* = –1.82, *p* = .07. Children again showed longer go-past times in the TL than ID condition, *b* = –0.21, *SE* = 0.04, *t* = –5.72, *p* < .001, while adults did not, *b* = –0.06, *SE* = 0.04, *t* = –1.82, *p* = .07.

Children showed no TL preview benefits when the positions of the first and second letters were exchanged over CTL previews except in single fixation durations. They also took longer to process target words in the TL than in the ID condition. Adults, however, did not show a TL-initial preview benefit in any of the four eye movement measures and, with the exception of single fixation, showed no processing deficit in the TL-initial over the ID preview condition. This suggests that the TL-initial preview benefit was absent in both children and adults with the exception of single fixation for children.

Internal TL effects. In single fixation, children showed a significant 29 ms TL preview benefit effect with longer single fixation durations in CTL-internal than TL-internal conditions, *b* = –0.10, *SE* = 0.03, *t* = –2.96, *p* < .001. For adults there was also a significant 20 ms TL preview benefit effect in the internal position, *b* = –0.09, *SE* = 0.03, *t* = –3.26, *p* < .001, and there was no significant interaction for internal position TL preview benefit and age group, *b* = –0.01, *SE* = 0.04, *t* = –0.13, *p* = .90. While children showed longer single fixation durations in the TL than ID condition, *b* = –0.07, *SE* = 0.03, *t* = –2.21, *p* = .03, single fixations did not differ between TL and ID conditions for adults, *b* = 0.01, *SE* = 0.03, *t* = 0.38, *p* = .70. In first fixation duration children showed no significant TL preview benefit effect,

b = –0.02, SE = 0.03, t = –0.70, p = .49, while adults showed a significant 17 ms TL preview benefit effect, b = –0.08, SE = 0.03, t = –2. 63, p = .01. There was, however, no significant interaction between TL preview benefit and age group, b = 0.06, SE = 0.04, t = 1.34, p = .18. Again, children had longer first fixations in the TL than ID condition, b = –0.07, SE = 0.03, t = –2.42, p = .02, and the adults showed no difference between conditions, b = 0.02, SE = 0.03, t = 0.55, p = .58. In gaze duration, the pattern of results was exactly as in first fixation with no TL preview benefit effect for children, b = –0.05, SE = 0.03, t = –1.54, p = .12, and a significant 16 ms TL preview benefit for adults, b = –0.07, SE = 0.03, t = –2.19, p = .03, and there was no significant interaction of TL preview and age group, b = –0.02, SE = 0.05, t = –0.43, p = .67. Children again had longer gaze durations in the TL than ID condition, b = –0.09, SE = 0.03, t = –2.68, p = .01, while adults had similar gaze durations in both conditions, b = 0.02, SE = 0.03, t = 0.55, p = .58, and there was a significant interaction between the TL over ID preview benefit effect and age group, b = –0.11, SE = 0.05, t = –2.29, p = .02. Unlike the earlier measures, there were no TL preview benefits in go-past time for children, b = –0.04, SE = 0.04, t = –1.02, p = .31, or adults, b = –0.06, SE = 0.04, t = –1.64, p = .10. However, go-past time was significantly longer for children in the TL than ID condition, b = –0.10, SE = 0.04, t = –2.74, p = .01, while it was not for adults, b = 0.01, SE = 0.04, t = 0.27, p = .79, which was also evident in the significant interaction of the ID over TL preview benefit and age group, b = –0.11, SE = 0.05, t = –2.14, p = .03.

Children again showed no TL preview benefit when the positions of the second- and third letters were exchanged compared to CTL previews, with the exception of the single fixation measure. Children also took longer to process targets in the TL than ID condition in all eye movement measures, suggesting that the letter transposition interfered with word identification processes. Adults, on the other hand showed TL preview benefits in single fixation, first fixation and gaze duration. This suggests that while adults made use of flexible letter identity codes of internal bigrams in the parafovea to facilitate word recognition, children only show this flexibility in single fixation duration. Indeed, adults do not appear to be slowed in word identification by internal letter transpositions while children incur a severe processing penalty.

DISCUSSION

In the present study, children and adults read sentences with manipulated previews using the boundary eye tracking method. The embedded target words were presented as previews with PsH, capitalisation or TL manipulations compared to CTLs to assess the readers' sensitivity to phonological and orthographic information in the parafovea. Our results present three important findings. First, we were able to show evidence of parafoveal processing in both children and adults using the boundary eye tracking method which has so far only been implemented in very few other studies with children (Häikiö et al., 2010). Second, we found a very clear pattern of results suggesting that children used phonological information in the parafovea to facilitate word recognition processes while adults did not, which is consistent with both theoretical models of reading development and empirical findings of masked priming studies. Third, our results suggest that while adults used orthographic information to facilitate parafoveal processing, children only exhibited orthographic preview benefits when targets received single fixations and when the capitalisation of nouns was manipulated. However, children showed a clear processing cost when previews contained orthographic manipulations compared to ID previews.

In regard to phonological processes we found greater preview benefits for children in single fixation and gaze duration measures from PsH previews than non-homophonic CTL previews, which were controlled for orthographic similarity to the target word. This suggests that children are able to extract phonological information from the parafovea to facilitate word identification processes, showing that phonological effects evident in masked priming experiments can also be found in parafoveal processing studies. There was, however, no evidence of a phonological preview benefit for adults. This finding is at odds with boundary method studies conducted in English and French but fits well with recent cross-lingual comparisons (Ziegler et al., 2010) which suggest that the importance of phonological processes in reading differs as a function of orthographic transparency. Nevertheless, as the present experiment employed materials appropriate for children with short, high-frequency target nouns, our results do not rule out that skilled adult readers may show phonological effects in German when reading more demanding stimuli. However, even in English, it has been found that parafoveal PsH effects in adults may depend on the timing of the preview manipulations in reading and naming tasks (Lee, Kambe, Pollatsek, & Rayner, 2005). Moreover, German has highly regular grapheme–phoneme correspondence rules which facilitate phonological decoding, while opaque languages such as English and French present readers with less consistent grapheme–phoneme correspondences. Longitudinal studies have shown that reading acquisition progresses at a much faster rate in transparent orthographies such as Spanish and Czech than in opaque languages such as English (Caravolas, Lervåg, Defior, Málková, & Hulme, 2013). Whether PsH preview benefit effects can also be found in skilled adult readers in orthographically shallow languages with more demanding reading materials will, however, require further studies with experimental variations of stimuli difficulty.

The results of the capitalisation preview manipulation were also very clear. Adults' reading processes were not adversely affected when the case of the initial letter of the preview was not consistent with that of the initial letter of the target word. Children, in contrast, had shorter fixation durations on target words following a capitalised preview than non-capitalised preview. This finding is an important addition to the previous boundary method experiments which tested capitalisation previews with adults. Hohenstein and Kliegl (2013a, 2013b) did not find capitalisation preview effects in either experiment for skilled adult readers. The capitalisation preview effect can be interpreted either as a facilitatory effect of capitalisation or as a preview cost of the visual mismatch. The facilitatory account the capitalisation benefit found for children suggests that noun capitalisation is used as a cue for lexical class which facilitates lexical access. As children learn noun capitalisation as an explicit part of their German reading education, this seems a plausible explanation. However, it is also possible that the effect is simply a cost of the visual mismatch of upper- and lower-case initial letters in the preview. It is also possible that capitalisation is used as a visual cue to direct more attention to the upcoming word. Indeed, a recent study by Rayner and Schotter (2014) was able to show a semantic preview benefit in English when target nouns where capitalised, suggesting that the capitalisation draws attentional resources and facilitates parafoveal processing. Whether or not one or a combination of these alternative accounts is more accurate, our results clearly show that noun capitalisation plays a role in parafoveal processing for beginning readers in German while adults appear to use flexible letter encoding which is unaffected by capitalisation.

We also found differing patterns of results for TL previews between children and adults. There were significant TL preview benefit effects for adults in internal word position for single fixation, first fixation and gaze duration measures, consistent with earlier findings (Dare & Shillcock, 2013; Johnson et al., 2007). In fact, adults showed identical benefit from ID and TL-internal previews. The TL-initial preview benefit was, however, only evident in single fixation duration. This is consistent with other findings that TL priming effects are weaker when external letters are involved (Perea & Lupker, 2003) and that TL-initial preview benefits for adults are much weaker than for TL-internal previews (Johnson et al., 2007). Children, on the other hand, showed no evidence of TL-internal or TL-initial preview benefit in the measures of first fixation, gaze duration or go-past time. The only exception was the single fixation measure, in which children showed both TL-internal and TL-initial preview benefits. However, the TL effects in single fixation duration for children should be interpreted with caution. We know that children generally show more and longer fixations during reading as well as more refixations on words, with the consequence that fewer words receive single fixations (Blythe & Joseph, 2011; Reichle et al., 2013) which is also evident in our data. We interpret the pattern of results to indicate that while adults make full use of flexible orthographic information in the parafovea, children generally do not have the same level of flexibility, while some children with stronger reading ability may already show a more adult use of orthographic information in single fixation duration. Further evidence for this account of our results can be found in the comparisons of the ID and TL-internal conditions. While adults show no processing penalty for internal TL previews, children show numerically longer fixation durations in all measures and significantly longer gaze durations and go-past times for TL-initial than ID conditions. This strongly suggests that children are more adversely affected by internal letter transpositions because of their greater reliance on letter position information than adults. Our results for orthographic preview effects in German thus suggest that adults use flexible letter codes in the parafovea to facilitate word identification, while children only show orthographic preview benefit under certain conditions. Children, however, had a greater preview benefit from capitalised than non-capitalised previews while adults draw parafoveal preview benefit independently of capitalisation.

Taken together we were able to demonstrate that children show strong phonological preview effects and appear to be sensitive to noun capitalisation. Children only showed TL effects in single fixation durations. Adults showed stronger preview benefit effects of TLs within words than at their beginnings, suggesting a more flexible encoding of internal than initial letter identity. We also found that adults reading in German did not appear to depend on phonological information and replicated the finding of earlier studies that parafoveal preview benefit is unaffected by capitalisation in German (Hohenstein & Kliegl, 2013a, 2013b).

The central contributions of the present study lie in providing evidence that children show phonological preview while adults show TL preview benefit, using the boundary method and age-appropriate materials for children. However, we also see possibilities to extend our findings. First, we conducted the PsH and TL preview experiments using very controlled stimulus materials. This had the consequence that we were only able to include a limited number of manipulations. It would be interesting to investigate whether there are differences in PsH preview effects using consonant changes rather than vowel changes in German and whether the position of the homophonic grapheme in the preview (e.g., initial, internal or final) influences the preview benefit. Similarly, it would be informative to investigate TL effects at positions further from the initial letter of a word, which would involve longer stimulus target words. As the visual span of adults and children have been shown to differ as a function of their reading development (Häikiö et al., 2009; Rayner, 1986), it is plausible that TL preview effects may be located closer to the initial letter of a word for beginning readers and shift to further internal letters in more skilled adult readers as they are able to process a wider parafoveal region.

A second related point is that the stimuli employed in the present study differed between phonological and orthographic manipulation experiments. This made it more difficult to directly compare PsH and TL preview benefit effects and their interaction with age group. It is plausible that PsH preview benefit effects might be greater than TL effects in children, as they are still predominantly reliant on phonological processes. A shift towards larger TL effects, which we found in adults, might be found in a developmental trend.

Finally, our goal was to compare the parafoveal processing of phonological and orthographic information in children and adults to identify developmental changes in the use of parafoveal information. Our results do suggest differences in the use of phonological information which we predicted based on developmental models of reading acquisition. However, to make stronger claims about the development of parafoveal processes will require longitudinal studies of children's parafoveal processes over their first years of reading education.

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APPENDIX

TABLE A1
Target words, pseudohomophone and control previews

Target	*Pseudohomophone*	*Control*	*Target*	*Pseudohomophone*	*Control*
Feld	Fäld	Föld	Blech	Bläch	Blüch
Fest	Fäst	Föst	Brett	Brätt	Brött
Geld	Gäld	Güld	Dreck	Dräck	Dröck
Hecht	Hächt	Hücht	Knecht	Knächt	Knücht
Nest	Näst	Nüst	Krebs	Kräbs	Kröbs
Netz	Nätz	Nötz	Specht	Spächt	Spücht
Pech	Päch	Püch	Speck	Späck	Spück
Recht	Rächt	Rücht	Steg	Stäg	Stüg
Rest	Räst	Rüst	Stern	Stärn	Stürn
Senf	Sänf	Sünf	Zwerg	Zwärg	Zwörg
Beil	Bail	Buil	Bahn	Baan	Baen
Bein	Bain	Boin	Brei	Brai	Broi
Geist	Gaist	Goist	Fahrt	Faart	Faert
Keim	Kaim	Kuim	Kleid	Klaid	Kluid
Leim	Laim	Loim	Lehm	Leem	Leam
Reis	Rais	Ruis	Mehl	Meel	Meol
Seil	Sail	Suil	Preis	Prais	Pruis
Teich	Taich	Tuich	Stein	Stain	Stuin
Teig	Taig	Tuig	Streich	Straich	Struich
Wein	Wain	Wuin	Streik	Straik	Struik
Zelt	Zält	Zült	Streit	Strait	Stroit

TABLE A2
Target words, lower-case, transposed-letter and control previews

Target	*Lower case*	*TL-initial*	*CTL-initial*	*TL-internal*	*CTL-internal*
Band	band	Abnd	Khnd	Bnad	Bced
Bart	bart	Abrt	Ecat	Brat	Bnet
Berg	berg	Ebrg	Ahrg	Breg	Bnag
Blut	blut	Lbut	Jhut	Bult	Boft
Brot	brot	Rbot	Kfot	Bort	Bent
Burg	burg	Ubrg	Ohrg	Brug	Bnog
Dorf	dorf	Odrf	Uhrf	Drof	Dnuf
Duft	duft	Udft	Ohft	Dfut	Dlot
Flug	flug	Lfug	Jtug	Fulg	Fotg
Flur	flur	Lfur	Jtor	Fulr	Fotr
Form	form	Ofrm	Utrm	From	Fnum
Gift	gift	Igft	Jpft	Gfit	Glet
Glas	glas	Lgas	Jpas	Gals	Gefs
Gold	gold	Ogld	Upld	Glod	Gtud
Grab	grab	Rgab	Fpab	Garb	Genb
Gras	gras	Rgas	Bpas	Gars	Gens
Heft	heft	Ehft	Abft	Hfet	Hlat
Herd	herd	Ehrd	Abrd	Hred	Hnad
Holz	holz	Ohlz	Ublz	Hloz	Htez
Horn	horn	Ohrn	Ubrn	Hron	Hcen
Kerl	kerl	Ekrl	Ahrl	Krel	Kval
Korb	korb	Okrb	Uhrb	Krob	Ksab
Pult	pult	Uplt	Oglt	Plut	Pfot
Rand	rand	Arnd	Ecnd	Rnad	Rvod
Sand	sand	Asnd	Ernd	Snad	Srod
Sarg	sarg	Asrg	Ecrg	Srag	Scog
Turm	turm	Utrm	Ofrm	Trum	Tvom
Wolf	wolf	Owlf	Umlf	Wlof	Wtef
Zelt	zelt	Ezlt	Arlt	Zlet	Zfot
Zorn	zorn	Ozrn	Usrn	Zron	Zcun
Blatt	blatt	Lbatt	Jhatt	Baltt	Beftt
Blitz	blitz	Lbitz	Jhitz	Biltz	Buftz
Brett	brett	Rbett	Dfett	Bertt	Bactt
Brust	brust	Rbust	Dhust	Burst	Bocst
Druck	druck	Rduck	Bhuck	Durck	Dosck
Durst	durst	Udrst	Obrst	Drust	Dcost
Ernst	ernst	Renst	Banst	Enrst	Escst
Fleck	fleck	Lfeck	Jteck	Felck	Fatck
Fluch	fluch	Lfuch	Jtuch	Fulch	Fotch
Glück	glück	Lgück	Jpück	Gülck	Göfck
Gruft	gruft	Rguft	Bpuft	Gurft	Gosft
Grund	grund	Rgund	Bpund	Gurnd	Gosnd
Kampf	kampf	Akmpf	Ehmpf	Kmapf	Kwopf
Kelch	kelch	Eklch	Ablch	Klech	Kfach
Klang	klang	Lkang	Jbang	Kalng	Kefng
Knall	knall	Nkall	Vhall	Kanll	Kecll
Knopf	knopf	Nkopf	Vbopf	Konpf	Kurpf
Krach	krach	Rkach	Bhach	Karch	Kench

(*Continued*)

Target	*Lower case*	*TL-initial*	*CTL-initial*	*TL-internal*	*CTL-internal*
Kraft	kraft	Rkaft	Bhaft	Karft	Kecft
Kunst	kunst	Uknst	Obnst	Knust	Krost
Markt	markt	Amrkt	Ewrkt	Mrakt	Mcekt
Milch	milch	Imlch	Jwlch	Mlich	Mfuch
Prinz	prinz	Rpinz	Bginz	Pirnz	Pusnz
Punkt	punkt	Upnkt	Ognkt	Pnukt	Prokt
Sumpf	sumpf	Usmpf	Ocmpf	Smupf	Swopf
Trank	trank	Rtank	Bfank	Tarnk	Tesnk
Tritt	tritt	Rtitt	Bfitt	Tirtt	Tustt
Trost	trost	Rtost	Bfost	Torst	Tenst
Wurst	wurst	Uwrst	Omrst	Wrust	Wcost
Zweck	zweck	Wzeck	Mveck	Zewck	Zamck