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Eye Movements Reveal Interplay Between Noun Capitalization and Word Class During Reading

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Abstract

Subjects' eye movements were recorded while they read sentences for comprehension. Sentences were presented with capitalized nouns—in agreement with German spelling rules—or completely in lowercase. Overall reading speed was not influenced by the manipulation of capitalization, but fixation durations were affected by the interplay between capitalization and the word classes of the fixated and the succeeding word. As expected, fixations were shorter for capitalized than lowercase nouns, but unexpectedly they were longer when the upcoming word was also a noun. This modulation was reduced when all words were printed completely in lowercase. We interpret the results as evidence for distributed processing across several words.

Keywords: eye movements; reading; corpus analysis; capitalization; parafoveal processing

Introduction

The uptake of visual information is critical for the process of reading. Most visual receptors are located in the fovea—the central 2° of the visual field. As distance from the fixation location (and thereby from the fovea) increases, acuity decreases across the parafoveal region. Hence, it is necessary to move our eyes to obtain visual information of the words in a sentence. Foveal information of the currently fixated word is most essential for word processing. There is much evidence for the effect of, among others, orthographic, phonological, and semantic features of the currently fixated, foveal word as well as of the not-yet fixated, parafoveal word on fixation durations. Some of the parafoveal effects are still under dispute (for a recent review see Schotter, Angele, & Rayner, 2012). The resolution of such disputes is critical for our understanding of eye-movement control during reading, because arguably parafoveal word processing is the primary source of information for guiding the eyes to the next fixation location.

Capitalization

Although many studies have demonstrated the relevance of low-level orthographic features on eye movements during reading, little is known about the role of *capitalization*. In languages based on the Roman alphabet, the first words of a sentence and proper nouns are capitalized, that is these words are spelled with an initial capital letter. Additionally, *German* script has an unusual characteristic: the capitalization of all nouns. Therefore, the frequency of capitalized words in German texts is relatively high, making it an ideal language for studying the impact of initial capital letters during natural reading.

Capitalized characters in parafoveal vision may be salient and attract attention to the preview word. Furthermore, German capitalization may reduce the cost of lexical processing. From the first letter alone, readers of German script obtain the word-class information (i.e., whether the next word is a noun vs. non-noun). Deeper lexical (e.g., semantic) processing of the word may start faster than in other languages because of the early availability of word-class information. Preprocessing of parafoveal words appears to be more likely in German than in less transparent orthographies (Laubrock & Hohenstein, 2012).

There is research demonstrating a beneficial influence of capitalization on reading rate in German (Bock, 1989; Bock, 1990; Bock, Augst, & Wegner, 1985; Bock, Hagenschneider, & Schweer, 1989; Gfroerer, Günther, & Bock, 1989). When uppercase and lowercase letters were used improperly, the reading rate was lower than when the German capitalization rules were observed (Bock et al., 1985). When Dutch subjects were asked to read German texts, they showed the same pattern of reading speed despite the absence of capitalization in Dutch (Bock et al., 1989). These effects were also reflected in eye-movement measures (Gfroerer et al., 1989). Furthermore, German subjects' reading rates for English texts were the same whether the rules of capitalization applied were based on German or English spelling (Bock et al., 1989), indicating that German readers transferred their familiar capitalization rules to text in a different language.

The advantage of capitalization increases with reading skill (Bock, 1990). For 10th-grade students, the effects of violations of German capitalization rules are similar to those obtained with adult readers. The same pattern was also present for 7th-grade children, but differences were less pronounced. Violation of the capitalization rule had no reliable effect on the reading speed of 3rd-grade children. In addition, on the basis of several experiments, Bock (1989) argued that the function of German capitalization rules for reading is independent of word shape, and that they allow differentiating between nouns and non-nouns without analyzing a word's meaning.

There is also evidence for the importance of capitalization in Italian. In Italian, like in most languages based on the Roman alphabet, proper names are spelled with an initial capital letter, whereas common nouns are spelled in lowercase. Peressotti, Cubelli, and Job (2003) demonstrated that reaction times in a lexical-decision task are reduced if proper names are presented capitalized compared to non-capitalized presentation and common nouns. The authors provide an orthographic cue hypothesis that an initial uppercase letter helps pre-activate lexical units corresponding to proper names.

Furthermore, Müsseler, Nisslein, and Koriat (2005) reported an influence of German capitalization rules on the missing-letter effect. Typically, when subjects are asked to underline a certain target letter, the letter is more difficult to detect in function words than in content words. In their study, this missing-letter effect was eliminated when function words within a sentence were capitalized indicating that unfamiliar orthography facilitates the extraction of single letters.

Finally, nouns are best recognized when they are presented with an initial uppercase letter (Jacobs, Nuerk, Graf, Braun, & Nazir, 2008). In this study, subjects had to type single words that were presented briefly (50 ms) and then followed by a mask. Words were presented with all letters in lowercase, with all letters in uppercase, or with an initial uppercase letter. Accuracy for non-nouns was best when they were presented with an initial uppercase letter or completely in lowercase (both types of presentation are common in German texts due to the capitalization of words at the beginning of a sentence).

Hohenstein and Kliegl (in press; Experiment 2) manipulated capitalization in an eye-movement study of semantic processing of parafoveal words. They asked subjects to read single German sentences for comprehension. Employing the gaze-contingent boundary paradigm (Rayner, 1975), the parafoveal preview for a critical target noun (*wool*) was semantically either related (*silk*) or unrelated (*soap*) to the target and was replaced with the target word during the saccade to the target location. Fixation durations on the target noun were shorter for related compared to unrelated previews, indicating parafoveal semantic information extraction. Most importantly, this effect was not modulated by capitalization: There was no significant difference between sentences presented completely in lowercase and sentences presented in agreement with the German capitalization rules (i.e., with capitalized nouns).

Hohenstein and Kliegl (in press) also analyzed the effect of capitalization on fixation durations on the target word, which was always a noun, and on the pretarget word, which was any of a number of different parts of speech, but never a noun. Whereas the violation of German noun-capitalization was reflected in longer target fixations, the pretarget was fixated more briefly if the sentence was presented completely in lowercase. This inverse effect of capitalization on pretargets and targets could not be explained by either (1) a general reading-speed benefit associated with a presentation in which nouns are capitalized—a common result of past studies—or (2) a unique effect of capitalization on reading nouns, but not words which are always presented in lowercase. We hypothesize that the obtained effect is due to an interplay of capitalization and the word classes (nouns/non-nouns) of fixated and parafoveal words.

Here we report an eye-movement corpus analysis of German sentences, which were presented either completely in lowercase or with capitalized nouns (following the German spelling rules). The focus will be on the interaction between the word class of the preceding, current, and upcoming word and capitalization.

Method

This is a reanalysis of the study of Hohenstein and Kliegl, (in press; Experiment 2). We describe the main features of the experiment, judged to be relevant for an appreciation of the present article; for further technical details we refer to the original article.

Subjects

Thirty-two subjects (20 women, 12 men) participated in the experiment. Their age was between 16 and 39 (M = 23, SD = 4.8). All were native speakers of German with normal or corrected-to-normal vision.

Apparatus

Sentences were displayed on a single line at midscreen height on a 21-inch monitor. Subjects were seated 24 inches in front of the screen. Sentences were presented in black, boldface, 20-point Courier New font on a white background. Each character was 12 pixels wide—0.45° of visual angle—at a screen resolution of 1024 × 768 pixels. The refresh rate of the monitor was 150 Hz.

Eyes were monitored using an EyeLink II system with a sampling rate of 500 Hz, an instrumental spatial resolution of 0.01°, and an average accuracy of better than 0.5°. Recording was binocular. Heads were positioned on a chin rest to minimize head movements.

Material

We used the material developed by Hohenstein, Laubrock, and Kliegl (2010). All sentences were constructed around a critical target region and ranged from six to thirteen words. In 100 sentences, the target word was a noun and the preceding word (i.e., the pretarget) was a non-noun. In 24 additional sentences, targets were non-nouns. The sentences did not include any punctuation except the period at the end. Word lengths ranged from two to eighteen characters.

Sentences were presented in two conditions: capitalized and non-capitalized. In the capitalized condition, the sentence's first word and all nouns were spelled with an initial capital letter. In the non-capitalized condition, all words were spelled in lowercase.

Procedure

Subjects were naive concerning the purpose of the experiment. They were instructed to read single sentences for comprehension. A random sample of one third of the sentences was followed by a three-alternative multiple-choice question that was answered by clicking on one of the response alternatives. Ninety-five percent of all questions were answered correctly, indicating no serious comprehension problems.

At the beginning of the experiment, subjects were instructed that the experiment consisted of two parts. One part of the sentences was presented following the German capitalization rules and the other was presented completely in lowercase. Each part comprised 62 sentences, preceded by six practice sentences, which were not included in the analyses. Subjects were informed about the start of the second part.

When a sentence was initially presented, the preview (related or unrelated) occupied the target location. An invisible boundary located directly after the last letter of the pretarget word was present in each sentence. When either eye crossed the boundary, the preview word on the target position was replaced with the target word. The sentence remained in this final form until the end of the trial. The manipulation of the preview has no relevance for the present study.

Measures and Selection Criteria

Data from sentences with a blink or loss of measurement was used only until the point in time preceding the first loss and only if the loss occurred after the target region. Saccades were detected with a binocular velocity-based algorithm (Engbert & Kliegl, 2003; Engbert & Mergenthaler, 2006). Analyses were based on right-eye fixations.

This first level of screening led to a pool of 39,646 fixations. In a second level of data screening, we excluded the first and last fixations in sentences (7,830) and fixations on the first or last words of sentences (9,608). We used first-pass fixations only (i.e., excluding 5,930 fixations). This second level of screening left us with 24,302 valid within-sentence reading fixations. Our selection procedure is similar to data filtering in a large eye-movement corpus study (Kliegl, Nuthmann, & Engbert, 2006). We included all non-training trials. Results were not affected by the exclusion of trials with subsequent comprehension errors.

We computed gaze durations (the sum of all first-pass fixations), first-fixation durations, and single-fixation durations (for a definition of these measures, see Inhoff & Radach, 1998) for each word. Additional measures included refixation probability and relative landing position (i.e., the position of the first fixation). Furthermore, we calculated reading speed (words per minute) for each sentence.

Statistical analysis

Inferential statistics for effects on fixation durations are based on *linear mixed models* (LMMs) specifying subjects and sentences as crossed random factors (Baayen, Davidson, & Bates, 2008; Kliegl, Masson, & Richter, 2010). LMMs are much more resilient to data loss than the classical analysis of variance. Thus, these analyses are very powerful even for datasets with differences in the number of observations between subjects and items. Effects in models with continuous dependent variables were estimated with the *lme4* package (Bates, Mächler, & Bolker, 2012) in the *R* environment for statistical computing (version 2.15.2, 64-bit build; R Development Core Team, 2012). LMMs were fitted using the restricted maximum likelihood method.

We specified varying intercepts for both subjects and items. Furthermore, we included varying slopes associated with the effect of capitalization—the only experimental factor in the present study. The full model including variance components for all terms of the experimental design is preferred for statistical analyses (Schielzeth & Forstmeier, 2009). Coverage probability of confidence intervals associated with fixed effects is better for LMMs including random slopes than for models including intercepts only (Schielzeth & Forstmeier, 2009; Barr, Levy, Scheepers, Tily, 2013). With the additional inclusion of correlation parameters, models did not longer converge. Hence, these parameters were excluded. In a recent simulation study, Barr et al. (2013) demonstrated that models without random correlations are very similar to full models with respect to coverage probability and power. The authors rank both kinds of models in the first position of desirable model designs.

The primary fixed effects in the analyses were capitalization and the interactions between capitalization and the word classes of the preceding, the current, and the next word. Following the work of Kliegl et al. (2006), we included several additional covariates (word frequency, word length, saccade length, second-order polynomial of relative landing position), which have an influence on fixation durations in reading. The inclusion of these covariates reduced potential confounding for the word class predictors.

Continuous predictors were centered at their mean; relative landing position was centered at .5; the factor capitalization (*capitalized presentation* vs. *non-capitalized presentation*) entered the analysis as treatment contrast with capitalization as reference category (0 vs. 1) and the factors for word class (*non-noun* vs. *noun*) were specified as sum contrasts (−0.5 vs. +0.5).

We report regression coefficients together with p values based on Markov chain Monte Carlo sampling with 10,000 samples (Baayen et al., 2008). Based on analyses of model residuals, we decided to use the (natural) logarithm of all fixation-duration measures.

Results

Global Reading Speed

The analysis of reading speed tested only the effect of capitalization. Mean reading speed was 208 and 207 words per minute in the capitalized and non-capitalized condition, respectively. This difference was not significant ($\beta = 0.85$; $p = .78$). The result differs from findings in earlier studies, in

which subjects read reliably slower if capitalization rules were not followed (e.g., Bock et al., 1985).

Fixation Durations

The analysis of gaze duration (20,768 observations), first-fixation (20,816), and single-fixation duration (17,775) revealed the same pattern of effects. We present a detailed analysis of gaze durations only. Table 1 displays the results of an LMM analysis with gaze duration as dependent variable. There were several significant effects associated with word frequency, word length, landing position, and saccade length (see Table 1 for details).

The violation of German capitalization rules did not significantly influence gaze duration as a main effect, but there were several significant interactions associated with it. If the capitalization rules were followed, nouns were fixated more briefly than non-nouns. Interestingly, the word classes of the previous and the next word also had an effect on gaze duration: If the previous word was a noun, fixation time was shorter; if the next word was a noun, gaze duration was longer.

Most importantly, the interaction between capitalization and word class was significant both for the current and the next word. Figure 1 displays these interactions. As expected, a noun was fixated longer if the presentation was non-capitalized and thus with unfamiliar orthography. This trend was reversed with respect to the word class of the word to the right: Fixation duration was reduced if the next word was a noun and presented completely in lowercase. As is apparent from Figure 1, compared to reading under normal German capitalization conditions, fixation durations in sentences presented completely in lowercase are less modulated by properties of the fixated and surrounding text. These interactions were also significant for either first-fixation duration or single-fixation duration as dependent variable.

Additional Analyses of Reading Behavior

There was a small effect of capitalization on saccade length: Saccades were shorter by 0.157 characters ($p = .003$) if all words were presented in lowercase compared to the presentation following the German capitalization rules (means values: 6.20 vs. 6.35). The interactions between capitalization and words class had no significant effect on saccade length (all ps $> .07$). Initial landing position, skipping probability, regression probability, and refixation probability were not significantly influenced by capitalization or the interactions between capitalization and word class (all ps $> .18$).

Discussion

In the present study, subjects were asked to read sentences for comprehension. Sentences were presented in one of two capitalization conditions: In the capitalized condition, all nouns were spelled with an initial capital letter (following the German spelling rules); in the non-capitalized condition, all words were presented completely in lowercase.

Table 1: Estimates (regression coefficients) with associated standard errors and p-values as well as random-effect variances of a linear mixed-model corpus-analysis with log gaze duration as dependent variable.

	Dependent variable: log gaze duration		
Fixed effects	Estimate	SE	p
(Intercept)	5.43494	0.026	< .001
Log_{10} frequency			
Previous word	−0.02305	0.003	< .001
Current word	−0.07392	0.003	< .001
Next word	−0.00005	< 0.001	.100
Length^{-1}			
Previous word	−0.03763	0.039	.334
Current word	−0.41590	0.048	< .001
Next word	0.01321	0.031	.667
Relative landing position			
Linear trend	−6.78905	0.400	< .001
Quadratic trend	3.39784	0.400	< .001
Saccade length			
Incoming	0.02457	0.001	< .001
Outgoing	−0.02955	0.001	< .001
Capitalization (present vs. absent)	−0.00232	0.010	.815
Word class (non-noun vs. noun)			
Previous word	−0.02092	0.010	.042
Current word	−0.07053	0.011	< .001
Next word	0.09283	0.009	< .001
Capitalization × word class			
Previous word	0.00183	0.013	.883
Current word	0.05577	0.014	< .001
Next word	−0.07686	0.013	< .001

Random effects	Variance
Sentences	
(Intercept)	0.00154
Capitalization	0.00000
Subjects	
(Intercept)	0.02003
Capitalization	0.00129
Residual	0.13397

Note. All continuous predictors were centred. Frequencies were $\log_{10}$ transformed. For length, the reciprocal was employed. "Current", "previous", and "next" indicate variables associated with the fixated word, the preceding word, and the succeeding word, respectively. The × symbol indicates an interaction.

Neither fixation times nor reading speed was significantly affected by the violation of capitalization. This result is in contrast to findings in earlier studies (Bock, 1989; 1990; Bock et al., 1985; 1989). We hypothesize the different result is due to changes in communication technology over the last 20 years. The earlier studies were conducted in the 1980s, a time in which text messaging, e-mail, and virtual chat rooms

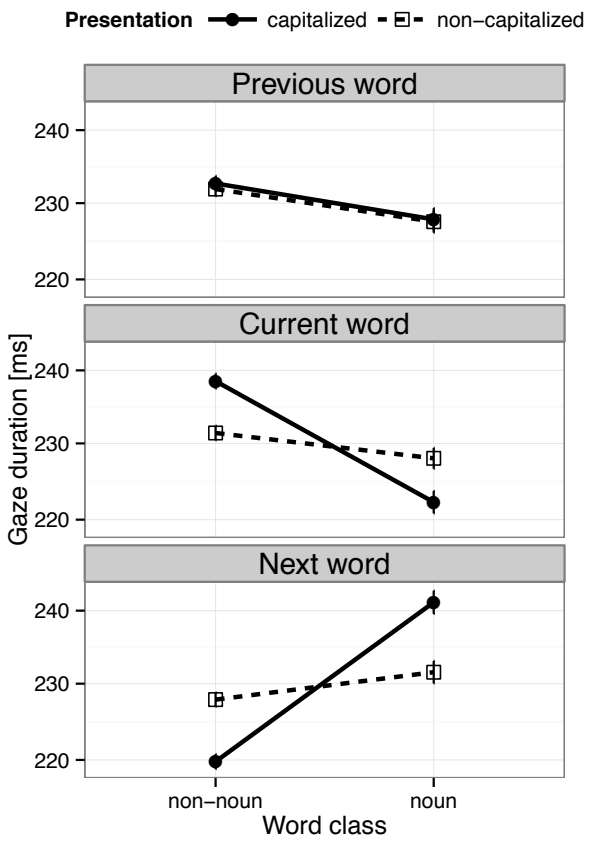

Figure 1: Gaze duration on the current word as a function of capitalization and word class of the previous, the current, and the next word. Error bars indicate standard errors. All random effects and all fixed effects except the intercept, capitalization, and word class (including interactions) were removed from the data. The removal of effects was applied to each panel separately.

were less widely used than they are today. The use of short text messages with cellphones, in particular, is easier when all words are typed in lowercase. Indeed Schloblinski et al. (2001) found that most German text messages by students do not follow the German capitalization rules. Furthermore, texts in lowercase could be found in e-mails and social networks too (e.g., Schnitzer, 2012). In the present study, participants were young adults. Hence, we suppose our subjects were more proficient in reading text without capitalization than subjects in the earlier studies.

The most important findings are the interactions between capitalization and the word classes of the fixated and the next word. We demonstrated that the effects in a critical target region (Hohenstein & Kliegl, in press) generalize to reading behavior throughout sentences. If German capitalization rules were followed, nouns were fixated more briefly than non-nouns. Interestingly, the effect was reversed for the upcoming word. We observed an effect of the parafoveal word on the current fixation duration. *Parafoveal-on-foveal* effects are an indicator of distributed processing of words during reading (e.g., Kliegl et al., 2006). The case of a word's first character is easy to extract due to the saliency of an uppercase letter in a string of lowercase letters. The direction of the effects could be explained by a segmentation hypothesis: The words preceding nouns are often highly associated with those nouns (e.g., articles, adjectives). Perhaps, when a non-noun is fixated and the next word is a noun, both words are processed during the fixation on the non-noun (the word-group hypothesis; Kliegl, 2007; Radach, 1996). This results in a slowdown if the next word is a noun. Once the noun is fixated, it has already been preprocessed and hence fixation time is reduced.

When all words were presented in lowercase, the effects of word class were significantly reduced. Reading was less modulated by the word class and appeared to be more homogeneous. Although reading speed is comparable in both capitalization conditions, the reading strategy is different because salient orthographic cues are missing when capital letters are not present. This finding is evidence for the importance of parafoveal processing in reading.

In summary, the results reveal an impact of orthographic and visual word features on distributed processing during reading. Furthermore, readers are very flexible in adapting to different reading situations. That said, our results do not generalize to older readers who might encounter problems in the unfamiliar reading situation. Besides age differences, future research should focus on how non-native speakers of German use capitalization cues for their reading strategies.

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