German Capitalization of Nouns and the Detection of Letters in Continuous Text

Jochen Müsseler, RWTH Aachen University
Monika Nißlein, Max Planck Institute for Human Cognitive and Brain Sciences
Asher Koriat, Institute of Information Processing and Decision Making, University of Haifa

Abstract The missing-letter effect refers to the phenomenon that letters are more difficult to detect in common function words (such as *the*) than in content words. Assuming that the missing-letter effect is diagnostic of the extraction of text structure, we exploited a special feature of German – the convention to capitalize the initial letter of nouns. Given the great flexibility of word order in German, it was proposed that this convention might help readers specify the structure of the sentence. Therefore orthographic variations that violate the capitalization rules should disrupt structure extraction and should result in a reduced missing-letter effect. The results indicated that: 1) capitalization of function words eliminated the missing-letter effect, but not at the beginning of a sentence; 2) A missing-letter effect occurred when the capitalization of the first letter was correct, but was followed by typecase alternation, and also when the size of the initial letters was relatively large for function words, but relatively small for content words. The results were discussed with respect to the possible contributions of visual familiarity, structural role, and processing time to the missing-letter effect, taking into account that a capitalized initial letter conveys significant information about the word class for German readers. Thus, the present results indicate that readers take advantage not only of function words but of any other information (here the capitalization of nouns) that helps to extract the structure of a sentence.

When readers are asked to circle a certain target letter while reading a text passage, they tend to miss that letter more often in function words, such as *the* or *for,* than in less frequent content words (for overviews, see Healy, 1994; Koriat & Greenberg, 1994). While this phenomenon, called the missing-letter effect, has been extensively replicated, there has been some controversy regarding its explanation. According to the original unitization account advanced by Healy and her associates (Healy, 1994), readers process text in parallel at the various levels of analysis available to them. Familiarity with a unit at the word level facilitates its processing by permitting access to its whole-word, unitized representation before the analysis of its constituent letters has been completed. Therefore letters are more difficult to detect in a familiar word than in a less familiar word. More recent versions of the unitization account also make assumptions about the time needed to process a word (Moravcsik & Healy, 1998): Word frequency, and thus the familiarity with its visual configuration and meaning, is assumed to affect the time to identify a word, and consequently the time available for identifying the constituent letters of that word (but for evidence contrary of the processing time hypothesis see Saint-Aubin, Klein, & Roy-Charland, 2003).

In contrast, Koriat and Greenberg (1994) argued that the missing-letter effect for frequent words such as *the*, *on,* and *for* derives from their function in text rather than from their high frequency (Koriat & Greenberg, 1994; Koriat, Greenberg, & Kreiner, 2002). According to their structural precedence hypothesis, function words are used early in text processing as important cues for establishing a tentative structural frame for the phrase or the sentence, but recede to the background in favour of semantically rich content words as the focus of processing shifts from structure to meaning. Thus, according to this view, letters in function words are missed because of the specific role of these words in conveying the structure of a sentence.

Hence, while the unitization account emphasized frequency and (visual) familiarity, the structural account stressed the grammatical role of words and the context that determines this role. As evidence mounted, however, it became clear that both views must be combined to account for the various findings. Saint-Aubin and Poirier (1997) were the first who favoured an integrative view of both accounts. More recently,

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Greenberg, Healy, Koriat, and Kreiner (2004) presented a model in which visual familiarity, structural analysis, and processing time conjointly contribute to the missing-letter effect for function words. According to this model, readers process text in parallel at several levels of analysis, which mesh the ease of identification with the role of function words as structural placeholders. It is assumed that unitization processes facilitate the identification of function words and aid to structurally organize the sentences. This organization guides attention and eye movements to the content words and thus enables on-line semantic analysis and integration. It remains possible, however, that particular orthographic features at the text surface primarily assist the identification processes while other features mainly serve as cues for the structural organization.

In the present study, we examine the role of such a particular orthographic feature. In German, as in English, the initial letter of the first word in a sentence is always capitalized. In addition, however, all nouns in a sentence are also capitalized, that is, printed with an initial capital letter. This distinctive visual feature allows nouns to be easily assigned to their proper grammatical class, distinguishing them from words belonging to other classes such as articles, prepositions, verbs, and adjectives. Indeed, Bock and colleagues (Bock, 1989; Bock, Augst, & Wegner, 1985) studied the extent to which the German rule of capitalizing nouns helps in reading. He reported that the correct use of uppercase and lowercase letters in German facilitates the specification of word class even without analyzing the meaning of the word. An irregular capitalization of the initial letter is assumed to activate wrong lexical units and therefore slows down word identification. Bock concluded that the German capitalization of nouns is helpful for readers because it differentiates between nouns and non-nouns on the text surface without the need to analyze the meaning of the words. In this way capitalization can support the formation of propositions.

In the experiments to be reported, we explored the possibility that orthographic variations that deviate from the capitalization rule in German, should affect the magnitude of the missing-letter effect. Thus, in a distorted version of text, some definite articles were capitalized, but some nouns were not. Two factors may contribute to a reduced missing-letter effect for the distorted version relative to a normal version. First, in accordance with the unitization account, any manipulation that impairs the overall shape of a function word, for example, *Der* (meaning "the" in German) instead of *der*, should improve letter detection because it slows down whole-word access, and prolongs processing time, so that more time is available to detect the constituent letters of the word (cf. Drewnowski & Healy, 1977; Healy & Drewnowski, 1983; but see Saint-Aubin et al., 2003). Note, however, that capitalized definite articles (*Der*) are not totally uncommon in German, because that is how they are written when they occupy the leading position in a sentence.

Second, deviant capitalization may also impair structure extraction. In fact, German allows far more flexibility of word order than other languages such as English, which should make it relatively difficult for a German reader to extract the structure of sentences on-line during reading (Müsseler, Koriat, & Nißlein, 2000). The convention to capitalize the first letter of a meaning-laden noun may therefore be particularly useful in aiding structural analysis, allowing easy assignment of some words to their proper grammatical class. A text that does not follow this convention may hinder structural analysis and might therefore improve letter detection. This would indicate that readers take advantage not only of function words but of other information that helps to extract the structure of the sentence.

The present experiments aimed to explore with the letter-detection task whether the capitalization of nouns in German fulfills a specific role in the extraction of sentential structure. A normal text version with correct capitalization was compared with a distorted version, in which some definite articles were capitalized, but some nouns were not. The critical nouns used in this study all began with the letter d. The critical function words were the definite articles *der* (masculine), *die* (feminine), and *das* (neuter; for a short explanation of the use of definite articles in German see Müsseler et al., 2000). In all experiments, participants searched for the letter d regardless of capitalization.

Experiment 1

Experiment 1 compared the missing-letter effect for a normal text version with that of a distorted version in which the initial letter of some definite articles was capitalized, whereas that of some nouns was not (see Figure 1 for an example). If German readers use capitalization of the first letter as a cue for word class, then typecase variation of this letter should have an effect on letter detection. Correct capitalization could help German readers extract the structural frame of a sentence. The capitalization of definite articles, however, should make it more difficult to use these words as keys for structure, so that rate of detection errors should decrease for these function words. In contrast, it is not clear whether the noncapitalization of nouns should affect the rate of detection errors. On the one hand, the noncapitalization of nouns could hinder their immediate classification as nouns in an early stage of processing and could therefore increase slightly the rate of letter-detection errors in these nouns. On the

		normal passages	distorted passages
critical words	nouns	Auch in der heutigen Zeit ist ein Dom ein Ort für einen Diakon sowie dessen Gebete. (Exp. 1-3) [Even in these days a cathedral is a place for a deacon and his prayer.]	Auch in der heutigen zeit Ist ein dom ein Ort Für einen Diakon sowie Dessen gebete. (Exp. 1) Auch in der heutigen ZeIt iSt ein DoM ein Ort fÜr einen Diakon sowie dEsSen GeBeTe. (Exp. 2) Auch in der heutigen zeit ist ein pom ein Ort für einen Diakon sowie dessen gebete. (Exp. 3)
	definite articles	Gerade für den Haushalt von Managern ist der Einsatz von einem guten Diener von großer Wichtigkeit. (Exp. 1-3) [Particularly for the household of managers the employment of a good servant is quite important.]	Gerade für den Haushalt von managern ist Der Einsatz von einem guten Diener von Großer wichtigkeit. (Exp. 1) Gerade für den Haushalt von MaNaGeRn ist dEr Einsatz von einem guten Diener von gRoSsEr WiChTiGkEiT. (Exp. 2) Gerade für den Haushalt von managern ist der Einsatz von einem guten Diener von großer wichtigkeit. (Exp. 3)

Figure 1. Examples of the materials used in Experiments 1-3. Critical words are underlined twice, control words are underlined once (Experiments 1 and 2 with font Times New Roman 13, Experiment 3 with font Geneva 13).

other hand, one could argue that the unfamiliarity of uncapitalized nouns requires additional processing time with the consequence of a better letter detection.

Method

Participants. Thirty-two University of Munich students, whose native language was German, were paid for participating in this study.

Stimulus materials. Twelve content-word sentences were constructed, each housing one of the following critical nouns: *Deo* (deodorant), *Dia* (slide), *Dom* (cathedral), *Dorf* (village), *Dank* (gratitude), and *Dach* (roof). Each of these nouns appeared in the singular, nominative case, that is, as a subject of a sentence. In parallel, 12 matched function-word sentences were constructed. Each of these had the same number of words as the matched content sentences, but used a definite article in nominative case at the same ordinal position as the critical noun in that sentence. The critical definite articles were *das* and *der*, *das* appearing in eight sentences, and *der* appearing in four sentences.

In addition, each sentence contained two control words, one noun and one definite article. The control words served to compare the detectability of target letters in the normal and distorted text version (see below). The capitalization of the control words was never changed, that is, they were correctly printed in both versions. The ordinal positions of control words were the same across each pair of matched content and function sentences. Because the number of three- and four-letter nouns in German is quite small, we used as control nouns five- and six-letter words, all beginning with *D*. As control articles, we used several forms of the definite article in the nominative, dative, and accusative case (*der*, *die*, *das*, *dem*, and *den,* see also Note 1). Each of the 24 sentences included other *d*s, in the first letter or the remaining part of words. However, these *d*s never appeared in the word that immediately preceded or followed a critical or a control word. Additionally, these *d*s were equally frequent in each pair of matched sentences. The critical and control words never appeared at the beginning or end of a sentence.

The 24 sentences were printed in font Times New Roman (point 13) on two pages and formed one passage consisting of unrelated sentences, with each sentence ending with a period. Two versions of this passage were formed, a normal and a distorted version. The normal version used normal capitalization throughout. In the distorted passage, all critical nouns were uncapitalized (e.g., *Deo* → *deo*), whereas all critical definite articles were capitalized (*der* → *Der*). The capitalization of some other words in the distorted sentences was also changed in order that the total number of capitalized words in each sentence would be equal across the distorted and normal version of each sentence (e.g., six capitalized words in the normal sentence, six capitalized words in its distorted version). The capitalization of the words appearing immediately before or

immediately after the critical and control words was not changed.

The sentences within the normal and distorted passages were randomly ordered and the critical words never appeared at the beginning or end of a line. Two filler sentences were added at the beginning and at the end of each page.

Procedure. Participants received written instructions for each passage. They were told to read each passage at their normal reading speed and to circle the letter *d* whether it appears in lowercase or uppercase. They were told that if they had missed a target, they should not retrace to circle it. In the case of the distorted version, participants were forewarned of the changes in capitalization. A short passage was given for practice. This passage included distorted capitalization in the case of the distorted version. All participants received both the normal and the distorted passages in counterbalanced orders. Participants were tested individually. Reading time for each passage was measured by the experimenter using a stopwatch.

Results

Reading times. Reading times were analyzed with a Text Type (normal vs. distorted) x Presentation Order (normal first vs. distorted first) analysis of variance (ANOVA). Mean word reading times were 469 ms. Neither Text Type, Presentation Order nor the interaction was significant. Thus, differences in reading time cannot account for the differences observed in error detection patterns. (Note that the time spent processing a word is not necessarily the time that this word is in foveal view. Postlexical integrative processing of a word is also possible while proceeding in reading the text, e.g., Rayner, 1998. In the present study, reading time is only measured as an indicator of whether the overall processing time differed between the normal and distorted text type.)

Letter detection in critical words. Figure 2 shows the mean percentage of detection errors for each condition. The calculation of the confidence intervals based on the method recommended by Masson and Loftus (2003) for within-subjects designs. Focusing first on the critical words, the pattern of results showed the typical missing-letter effect in normal passages, that is, fewer detection errors in nouns than in definite articles. In distorted passages, this effect was wiped out completely.

A Word Class (noun vs. article) x Text Type x Presentation Order ANOVA on the percentage of omission errors yielded significant effects for Word Class, $F(1, 30) = 19.48$, $MSE = 256.66$, $p < .001$, with definite articles producing a higher error rate (18.6%) than nouns (6.1%). Text Type also yielded a significant effect, $F(1, 30) = 21.90$, $MSE = 200.67$, $p < .001$, with higher error rates for the normal (18.2%) than for the distorted text (6.5%). More important, the Word Class x Text Type interaction was highly significant, $F(1, 30) = 33.72$, $MSE = 247.40$, $p < .001$. There was no main effect or interaction involving Presentation Order; therefore the means were collapsed across this factor.

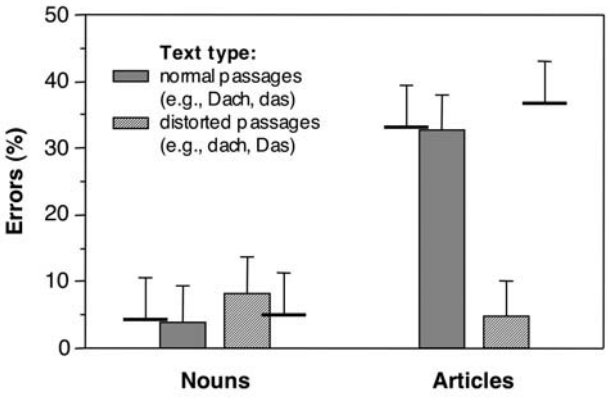

Figure 2. Mean percentage of detection errors for nouns and definite articles in Experiment 1. Strokes alongside the columns indicate detection errors in the control words. Error bars indicate 95% confidence intervals according to Masson and Loftus (2003).

In the present and all subsequent experiments, separate t-test analyses were conducted for four comparisons of means. The error rate of nouns and articles was compared in the normal and distorted passage, respectively; error rates of nouns and articles were additionally compared within text versions to examine the missing-letter effect. As a consequence, the a-level of significance was adjusted to $\alpha = .05/4 = .0125$ (two-tailed, Bonferroni adjustment).

T-test analyses confirmed that definite articles produced more detection errors than nouns in the normal passages, $t(31) = -5.93$, $p < .0125$, consistent with the missing-letter effect. The results for the distorted passages, in contrast, failed to reveal a missing-letter effect, $t(31) = 1.33$, *ns*. As can be seen in Figure 2, the error rates of nouns were not affected by the reversed capitalization (3.9% in normal passages vs. 8.3% in distorted passages), $t(31) = -1.87$, *ns*, but the error rate of definite articles was markedly affected (32.6% vs. 4.7%), $t(31) = 5.88$, $p < .0125$.

Letter detection in control words. Recall that control words were always capitalized correctly regardless of whether they were embedded in normal or in distorted text passages. Strokes in Figure 2 indicate fewer detection errors in nouns than in articles in both normal and distorted passages.

A Word Class x Text Type x Presentation Order ANOVA yielded a highly significant effect only for word class, $F(1, 30) = 40.21$, $MSE = 732.46$, $p < .001$. Omission rate was higher for function words (35.5%) than for content words (4.7%). Error rates in normal and distorted text passages did not differ significantly, $F(1, 30) = 1.26$, $MSE = 110.24$, *ns*, nor was there an interaction between Word Class and Text Type, $F < 1$. Again, there was no main effect or interaction involving Presentation Order. Collapsing across presentation orders, the control words yielded the typical missing-letter effect, regardless of the type of text (normal vs. distorted) in which they were embedded: Comparing error rates for the critical control words placed in normal text and in distorted text (all correctly capitalized) yielded a significant effect for word class, $F(1,31) = 48.16$, $MSE = 603.71$, $p < .001$, and no significant effects either for Text Type, $F(1,31) = 1.5$, $MSE = 151.56$, *ns*, or for the interaction, $F < 1$.

Discussion

Experiment 1 yielded two main results. First, reversed capitalization improved letter detection in definite articles to the extent of eliminating the missing-letter effect. The beneficial effect of capitalization on letter detection in the definite articles is consistent with previous findings reported by Healy and her associates (e.g., Healy, 1980; Healy & Drewnowski, 1983; Healy, Oliver, & McNamara, 1987) using other types of orthographic variations or misspellings, and support the claim that orthographic manipulations that impair the visual familiarity of highly frequent words reduce or eliminate the missing-letter effect. Note, however, that German readers are familiar with capitalized articles because they very often occur in the leading position of a sentence (see also Experiment 4). Consequently, the absence of the missing-letter effect for capitalized articles would rather seem to result from their violating a convention that implicates their syntactic role within the sentence. Perhaps German readers tend to interpret capitalized words as nouns when they do not occupy the initial position in a sentence. This implies a delicate sensitivity to the interaction between capitalization and syntactic slot (cf. Bock, 1989; Bock et al., 1985).

Second, the effects of capitalization did not generalize to the correctly capitalized words that were embedded in the distorted sentences. The size of the missing-letter effect was practically identical for the control words whether these appeared in the normal or in the distorted sentences. Recall that control words and the words that immediately preceded or followed a control word were correctly capitalized in both the distorted and undistorted versions. Thus, control words were always embedded in a normal text phrase. This may imply that the missing-letter effect is due to a process that does not extend beyond the phrase level (see also Müsseler et al., 2000). However, it is unclear whether the missing-letter effect observed for the control words derives from a word-level or phrase-level unit. If it emerged at the word level, this would lend some support for the unitization account of the missing-letter effect in terms of whole-word processing. In contrast, if it reflects a phrase-level analysis, this would lend some support for the structural account of sentence processing. Given this uncertainty, it is also not clear whether the letter-detection rates of the critical words were affected at the word or phrase level. The subsequent experiments were conducted in order to clarify this point.

Another problem in interpreting the results is that they could derive simply from the ease of detecting miscapitalizations. In particular, letter detection in definite articles improved when the articles were incorrectly capitalized. Then, perhaps, the capitalization manipulation affected letter detection primarily by signaling misspellings. Indeed, previous work has indicated that misspellings reduce the magnitude of the missing-letter effect (e.g., Healy et al., 1987, for *the* vs. *teh*). Further, words printed in capital letters in English have been found to attract greater attention in general than words printed in lowercase letters. Philipps (1979) and Sanocki (1991) found an attention priority for larger over smaller letters, and McClelland (1976), who used mixed-case words, found an advantage for those beginning with an uppercase letter over those beginning with a lowercase letter. Thus, it is unclear to what degree the results for nouns and distorted articles depend simply on the miscapitalized initial letter or the better detectability of uppercase letters. These issues are addressed in the following experiments.

Experiment 2

If indeed capitalization of the initial letter is used by German readers as a diagnostic cue for grammatical class, then manipulations that do not affect the initial letter of a word should perhaps be less detrimental to structural analysis than the change of capitalization used in Experiment 1. Thus, in Experiment 2, we kept the correct capitalization of the first letter for nouns (uppercase) and for the definite articles (lowercase), but alternated the case of the following letters (e.g., DaCh, *dEr*). This manipulation allows us to use critical words with a correct first letter, but with a strongly distorted word shape. If the improved letter detection of definite articles in Experiment 1 is due to the detection of miscapitalizations or an unfamiliar word shape, the results of Experiment 2 should yield a similar pattern to that of Experiment 1. The same prediction can be made

if the change of word shape disrupts the processing of critical words as whole-word units, inducing a letter-by-letter reading and a prolonged processing time. On the other hand, if the initial letter is used as a diagnostic cue for grammatical class, a missing-letter effect is predicted with this type of text distortion, contrary to Experiment 1.

Method

Participants. Twenty-six students were paid for participating in this study.

Stimulus materials. The same materials as in Experiment 1 were used. The normal version was the same, whereas the distorted version was created by preserving the correct capitalization of the first letter of the critical words and alternating the typecase of the letters that followed (e.g., *der* → *dEr*, *Dach* → *DaCh*; see Figure 1 for a detailed example). Capitalization of some other words in the distorted text was also changed in this way. Thus, the initial (target) letter of the critical words, nouns, and articles had the same capitalization in both the normal and the distorted text passages. As in Experiment 1, control words were capitalized correctly in both text passages.

Procedure. The procedure was identical to that of Experiment 1. Again, participants were forewarned of the changes in capitalization in the distorted text. A short passage that included alternate-case words was used for practice prior to the application of the distorted version.

Results

Reading times. Unlike in Experiment 1, mean reading times in Experiment 2 differed significantly for the two versions, $t(25) = 9.35$, $p < .001$. Reading times per word were longer for the distorted text (512 ms per word, referring to Masson & Loftus, 2003, the 95% confidence interval was between 499 and 524 ms) than for the normal text (434 ms per word, 95% confidence interval between 421 and 446 ms). However, because slower reading speed can be assumed to improve letter detection (e.g., Healy, 1976), the letter-detection differences of the present experiment could be even larger than they appear.

Letter detection in critical words. In the normal passages, mean detection errors indicate again fewer detection errors in nouns than in definite articles (Figure 3). In the distorted passages, a similar tendency is observed, but it seems somewhat reduced.

A Word Class x Text Type ANOVA on the percentage of omission errors yielded a significant effect for Word Class, $F(1, 25) = 32.17$, $MSE = 233.23$, $p < .001$, with target letters missed more frequently in definite articles (22.1%) than in nouns (5.1%). Text Type yielded no significant effect, $F < 1$, but the interaction was significant, $F(1, 25) = 5.68$, $MSE = 169.76$, $p < .05$. As can be seen in Figure 3, error rates for nouns did not differ significantly for the normal (3.5%) and distorted texts (6.7%), $t(25) = -1.48$, *ns*. Definite articles yielded somewhat more errors in the normal (26.6%) than in the distorted text (17.6%), although not significantly so, $t(25) = 1.72$, *ns*. More important, error rates for nouns and definite articles differed significantly in normal passages, $t(25) = -6.8$, $p < .0125$, and in distorted passages, $t(25) = -2.47$, $p < .0125$, one-tailed. Although the word shape was distorted strongly by the case alternation manipulation, a missing-letter effect was still observed in the distorted text.

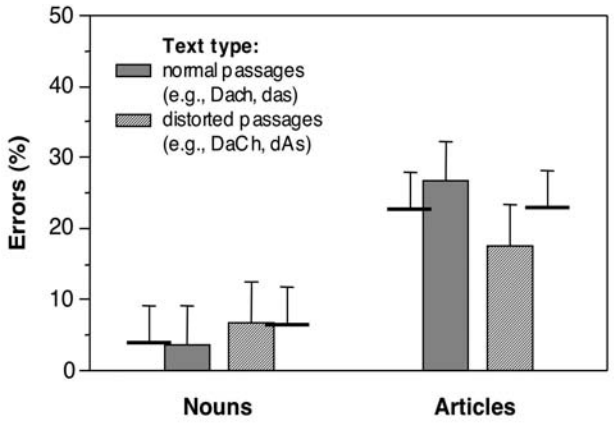

Figure 3. Mean percentage of detection errors for nouns and definite articles in Experiment 2.

A comparison of the results of Experiments 1 and 2 showed that error rates for the definite articles in the distorted text passages were clearly higher in Experiment 2 (17.6%) than in Experiment 1 (4.7%). In an Experiment (1 vs. 2) x Word Class (noun vs. article) x Text Type (normal vs. distorted) ANOVA, the between-subject factor of Experiment was not significant, $F < 1$. The main effects of both Word Class, $F(1, 56) = 50.81$, $MSE = 245.49$, $p < .001$, and Text Type, $F(1, 56) = 13.51$, $MSE = 226.44$, $p < .001$, were significant. The Experiment x Word Class interaction was not significant, but significant effects were obtained for the Experiment x Text Type interaction, $F(1, 56) = 4.94$, $MSE = 226.44$, $p < .05$, the Word Class x Text Type interaction, $F(1, 56) = 34.05$, $MSE = 208.32$, $p < .001$, and the three-way interaction, $F(1, 56) = 6.96$, $MSE = 208.32$, $p < .02$. Thus, letter detection in definite articles was strongly influenced by the type of distortion used. Definite articles with a correctly uncapitalized first letter yielded an inordinately high rate of omission errors

despite the strong distortion of word shape caused by case alternation.

Letter detection in control words. Detection errors in control words were analyzed with a Word Class x Text Type ANOVA. The only significant effect was the effect of Word Class: Letter detection in control nouns was better than in control articles, $F(1, 25) = 22.70$, $MSE = 359.11$, $p < .001$. The pattern of results is consistent with Experiment 1, indicating that the orthographic context in which the control words are embedded does not influence letter detection in the correctly capitalized words.

Discussion

Experiment 2 yielded a missing-letter effect in both the normal and the distorted text versions. Although a stronger missing-letter effect was observed in the normal text passage, error rates for nouns and articles differed significantly in the distorted passage as well. Thus, in contrast to Experiment 1, Experiment 2 produced a reduced, but still significant, missing-letter effect for the distorted words.

This result is consistent with some previous findings. Healy and Drewnowski (1983, Experiment 3), for example, found higher error rates for common words and common word suffixes than for rare words even with a case-alternation format. They attributed this effect to nonvisual factors (which they did not point out in detail), because familiar visual units larger than a letter are not available for words in mixed type case. On the other hand, Healy and co-workers (Drewnowski & Healy, 1977, 1980, 1982; Healy, 1980; Healy & Drewnowski, 1983) also found that case alternation reduces detection errors markedly, especially in common words.

Also, Besner (1989) found that shape distortion by case alternation impaired the perceptual identification of function words less than that of content words or nonwords. For speeded naming and lexical decision, in contrast, both types of words were impaired equally by case alternation. Besner (1989) and Cohen and Freeman (1978) reported that the effects of case alternation were not stronger for familiar than for unfamiliar words, suggesting that the effect occurs at an earlier stage (e.g., letter recognition) than that of access to word recognition units. Perhaps, as proposed by several authors (e.g., Smyth, Morris, Levy, & Ellis, 1990), word recognition units are activated by abstract letter identities that are indifferent to typecase. If word perception is mediated by preliminary letter identification (McClelland, 1976), a missing-letter effect is to be expected even for words printed in mixed cases, because the visual configuration of a word is affected, but not the arrangement of the letters. The results of Experiment 2 are consistent with this view. This would suggest that the effects of capitalization obtained in Experiment 1 derive from the tendency of German readers to use capitalization of the first letter of a word as a cue for word class (Bock, 1989; Bock et al., 1985). The implication is that orthographic variations that destroy whole-word shape need not have a uniform effect on letter detection. Rather, these effects should differ depending on the specific type of variation involved.

This conclusion receives support from the comparison of the results of Experiments 1 and 2, which yielded markedly different patterns of letter detection. In comparison to Experiment 1, the correct capitalization of the first letter in Experiment 2 increased the rate of detection errors in articles. Note that the orthographic distortions used in Experiment 2 differ substantially from that used in Experiment 1: Case alternation in Experiment 2 strongly destroys word shape, resulting in a completely unfamiliar visual pattern. In contrast, as already noted, capitalized articles in Experiment 1 are not that uncommon in German, because they can occur in the initial position of a sentence. Nevertheless, the unfamiliar visual word shape like *dEr* or *dAs* (Experiment 2) yielded a missing-letter effect whereas a familiar word shape like *Der* or *Das* (Experiment 1) did not. This result suggests that capitalization of the first letter plays a crucial role, probably because it is used by readers as a cue for word class.

Experiment 3

One problem with the previous experiments is that it could be argued that uppercase letters attract more attention than lowercase letters simply because of their larger size. In Experiment 1, this should be expected to improve detection of the letters that serve as targets in articles (e.g., *D* in *Der*), whereas in Experiment 2, it should decrease letter detection, because attention is directed not to the initial target position but to the second position (e.g., *d* in *dEr*). It could also be argued that in Experiment 2, the initial lowercase letters are laterally masked by the uppercase letter that follows (for a discussion of this hypothesis and other case mixing effects, see Besner & Johnston, 1989; Mayall, Humphreys, & Olson, 1997). Therefore, in Experiment 3, a different manipulation of word shape was used that does not affect capitalization, and avoids the possibility that lowercase letters are masked by the larger uppercase letters.

In Experiment 3, we kept the correct capitalization of words, but changed the shape of the first letters by varying the font size. The size of the capitalized *D* in nouns was reduced and the lowercase *d* in definite arti-

cles was enlarged (e.g., *D*ach vs. *D*ach, *d*er vs. *d*er). This manipulation allows us to use correctly capitalized words, but emphasizes visually the initial letter *d* in function words while making the capitalized *D* in content words less conspicuous. Correspondingly, enlarged target letters d should yield a better letter detection in articles, while reduced target letters *D* should yield a worse letter detection in nouns. Nevertheless, a missing-letter effect is predicted on the basis of the assumption that the correct use of the lowercase *d* as the initial letter in articles, even if it is enlarged, is diagnostic of word class. Consequently, definite articles could be more easily processed, leading to a higher rate of detection errors in these words than in nouns. However, we expect the missing-letter effect to disappear, if in the previous experiments the pure size of the uppercase letters simply attracted more attention, which entailed an improvement of letter detection in Experiment 1 and an impairment in Experiment 2.

Method

Participants. Thirty students were paid for participating in this study.

Stimulus materials. The same sentences as in Experiments 1 and 2 were presented in a normal and in a distorted passage. Text passages were now presented in font Geneva (13 point as normal size), because line width of each character varies as little as possible in this font. The correct capitalization of the words was preserved, but in the distorted version the size of the initial letters of definite articles was increased (plus 3 points) and that of nouns was reduced (minus 3 points). Because the line width of enlarged and reduced letters also changes with the size of the letters, the smaller initial letters of distorted nouns (and only those) were printed in bold in order to compensate for their reduced line width and to make them look like the other letters in the text. In this way, capital letters resemble small letters in size and width of line, but are nevertheless unambiguously distinguishable as capital letters, whereas the first letters of definite articles are clearly accentuated by size (see Figure 1 for examples).

Design and procedure. The design and procedure were the same as in Experiment 1.

Results

Reading times. Mean reading times per word were slightly longer for distorted (557 ms, 95% confidence interval between 544 and 570 ms) than for normal text (539 ms, 95% confidence interval between 526 and 552 ms), $t(29) = 1.97$, $p < .06$. Again, if slower reading speed can be assumed to improve letter detection, then the letter-detection differences observed in the present experiment represent an underestimate.

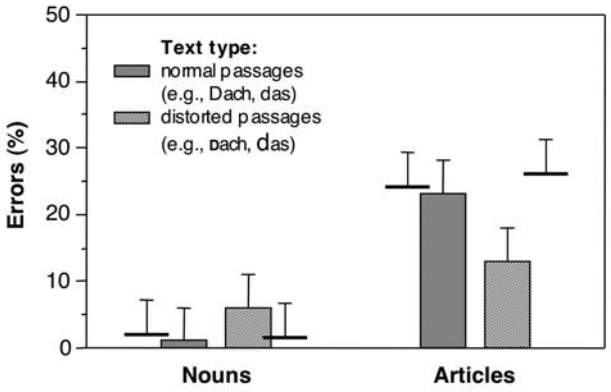

Figure 4. Mean percentage of detection errors for nouns and definite articles in Experiment 3.

Letter detection in critical words. The pattern of results was similar to Experiment 2 (Figure 4). Again, in the distorted passages fewer detection errors in nouns were observed than in definite articles, although this effect was smaller than in the normal passages.

Detection errors were analyzed with a Word Class x Text Type ANOVA. Again, target letters were missed more frequently in definite articles (18.1%) than in nouns (3.6%), $F(1, 29) = 17.86$, $MSE = 350.49$, $p < .001$. The Word Class x Text Type interaction was significant, $F(1, 29) = 21.89$, $MSE = 77.11$, $p < .001$. Error rate for nouns was lower in normal text than in distorted text, 1.1% vs. 6.1%, $t(29) = -2.69$, $p < .0125$, and the opposite result was obtained for the definite articles, that is, 23.1% versus 13.1%, $t(29) = 2.88$, $p < .0125$. Nevertheless, error rate was somewhat higher for definite articles than for nouns even in distorted passages, although only marginally significant $t(29) = 1.98$, $p < .03$, one-tailed. In fact, the rate of detection errors was about twice as large in articles than in nouns.

To further confirm this last result statistically, a between-experiment analysis was conducted. A comparison with the findings of Experiment 1 showed that error rates for the definite articles in the distorted text passages were again much higher in Experiment 3 (13.1%) than in Experiment 1 (4.7%). In an Experiment (1 vs. 3) x Word Class (noun vs. article) x Text Type (normal vs. distorted) ANOVA, the between-subject factor of Experiment was not significant, $F < 1$. The main effects of both Word Class, $F(1, 60) = 37.22$, $MSE = 301.30$, $p < .001$, and Text Type, $F(1, 60) = 16.99$, $MSE = 183.47$, $p < .001$, were significant. The Experiment x Word Class interaction was not significant, but signifi-

cant effects were obtained for the Experiment x Text Type interaction, $F(1, 60) = 7.17$, $MSE = 183.47$, $p \leq .01$, the Word Class x Text Type interaction, $F(1, 60) = 53.67$, $MSE = 160.90$, $p < .001$, and the three-way interaction, $F(1, 60) = 7.19$, $MSE = 160.90$, $p < .01$. Thus, letter detection in definite articles was strongly influenced by the type of distortion used. In the distorted versions, the enlargement in size of the first letter (Experiment 3) did not reduce the error rates to the same degree as did the incorrect capitalization of the first letter (Experiment 1).

Letter detection in control words. Detection errors in control words were analyzed with a Word Class x Text Type ANOVA. There was again a significant effect for Word Class, $F(1, 29) = 40.99$, $MSE = 403.85$, $p < .001$, so that function words yielded more detection errors than content words. There was no difference between control words embedded in normal text and those embedded in distorted text passages.

Discussion

In Experiment 3, the first letter of the critical nouns and articles was correctly capitalized in the distorted version, but the size of the initial letter was manipulated by emphasizing the target letter *d* in function words while making the target letter *D* in nouns less conspicuous. As was expected, letter detection was improved by this size manipulation in comparison to letter detection in the normal version.

Although the first letters of definite articles were clearly emphasized by enlarging their size, and the first letters of nouns were clearly made less easily detectable, almost twice as many omission errors were made in articles than in nouns. Again, in accordance with the structural account, it seems that the correct use of the lowercase *d* as initial letter in articles, even if it is enlarged, is diagnostic of word class. Consequently, definite articles produce more detection errors than in nouns. Somewhat inconsistent with the structural account, however, is the finding of increased error rate of nouns. If capitalization is used as a cue for word class and if letter detection is exclusively determined by this feature, letter detection in nouns should be independent of font size. The somewhat discrepant finding indicates that other factors contributed to the pattern of results.

In the present context, letter visibility and its influence on reading behaviour might play a role. For example, Schneider and Healy (1993), who manipulated the visual characteristics of the target letter by variations of font type, found more detection errors with the standard font (see also Saint-Aubin & Poirier, 1997, who found that the omission rate was due to the visual properties of the target letter). Tinker and Paterson (1955) analyzed the oculomotor behaviour during the reading of texts with various typographical font sizes. They found reading times to be slower for both larger and smaller font sizes as compared to a standard font size. The increased reading time of the larger font size was simply attributed to the printing space that is required by the enlarged font size and that forces the eye to make more fixations in covering the same amount of reading material. The smaller the font size, on the other hand, the greater the impairment in visibility and the nearer one gets to the threshold of visual discrimination. Taking these results into account, in Experiment 3 more errors should occur in distorted nouns and less errors in distorted articles as compared to normal text. This was indeed the case.

In all three experiments presented so far, the critical function and content words never occupied the first position in a sentence. However, as already pointed out, function words (but not nouns) in German have a different capitalization depending on their position within the sentence. In Experiment 4, we manipulated not only word shape, but also the position of critical words in the sentence.

Experiment 4

In Experiment 1, when capitalized articles (*Der* and *Das*) appeared within a sentence, the missing-letter effect was wiped out completely. As noted earlier, capitalized articles are not unfamiliar to German readers, because they occur at the beginning of a sentence. Is it then possible that the missing-letter effect is sensitive not only to the global shape of the article, but also to its position within the sentence? Would orthographic patterns such as *Der* and *Das* produce an inordinately high rate of omission errors when they occupy the first position in a sentence, although they yield no more errors than nouns when they appear in the middle of the sentence? If so, this may suggest a structural contribution to the missing-letter effect.

In German, an article usually precedes a noun, but nouns can also be placed in the first position in a sentence without an article. Consider the following examples:

1) Das *Datum*, die Uhrzeit und das Thema der Sitzung passen Dieter heute nicht in den Kram.
[The *date*, the time and the topic of the meeting are not convenient to Dieter today.]

2) *Datum*, Uhrzeit und Thema der Sitzung passen Dieter heute nicht in den Kram.
[*Date*, time and topic of the meeting are not convenient to Dieter today.]

		normal passages	distorted passages
critical words at the beginning of a sentence	nouns	Dame sein hieß im letzten Jahrhundert, sein feierliches Debüt bei dem Ball zu geben. [To be a lady in the last century implied to have a worthy debut at the ball.]	dame sein Hieß im letzten jahrhundert, Sein feierliches Debüt bei dem Ball zu geben..
	articles	Das schöne Gebäude wirkt im Dunst romantisch, als der Maler die Skizze beginnt. [The beautiful building looks romantic in the haze, when the painter begins the drawing.]	das schöne gebäude Wirkt im Dunst romantisch, Als der Maler die Skizze beginnt.
critical words within a sentence	nouns	Sein feierliches Debüt bei dem Ball zu geben, hieß Dame sein im letzten Jahrhundert. [To be a lady in the last century implied to have a worthy debut at the ball.]	sein feierliches Debüt bei dem Ball zu Geben, hieß dame sein Im Letzten jahrhundert.
	articles	Als der Maler die Skizze beginnt, wirkt das schöne Gebäude im Dunst romantisch. [The beautiful building looks romantic in the haze, when the painter begins the drawing.]	als der Maler die Skizze Beginnt, wirkt Das schöne gebäude im Dunst romantisch.

Figure 5. Examples of the materials used in Experiment 4. Critical words are underlined twice, control words are underlined once (font Times New Roman 13).

In Sentence 2, the definite articles of all three subjects (Datum, Uhrzeit, Thema, i.e., date, time, topic) are eliminated without any other changes in word order. Both types of sentences (1 and 2) are grammatically correct and they do not differ with respect to their content.

Additionally, word order is quite flexible in German (see Müsseler et al., 2000; Pechmann, Uszkoreit, Engelkamp, & Zerbst, 1996; Rösler, Pechmann, Streb, Röder, & Henninghausen, 1998) and it is possible to change the order of different phrases within a sentence without changing the meaning of the sentence. Consider the following examples:

3) Nicht in den Kram passen Dieter heute *Datum*, Uhrzeit und Thema der Sitzung.
[Not convenient to Dieter are *date*, time and topic of the meeting today.]

4) Nicht in den Kram passen Dieter heute das *Datum*, die Uhrzeit und das Thema der Sitzung.
[Not convenient to Dieter are the *date*, the time and the topic of the meeting today.]

Experiment 4 took advantage of the flexibility of word order in German to investigate whether the position of capitalized articles influences the missing-letter effect. According to the structural account, a missing-letter effect is expected for the definite article even when it occupies the initial position in a sentence (and is therefore capitalized, see Sentence 1). On the other hand, on the basis of the results of Experiment 1, we should expect no missing-letter effect for capitalized articles within a sentence, because capitalization falsely indicates word class. The original unitization account, in contrast, might predict little difference in detection rate of capitalized articles at the beginning of and within a sentence, because of their identical visual word shape.

Method

Participants. Thirty-two students were paid for participating in this study.

Stimulus materials. A new set of sentences was used in this experiment to take advantage of the options mentioned above. Eighteen matched pairs of sentences were constructed, one containing a critical noun without a preceding definite article (see Sentence 2 above) and one containing a critical definite article (see Figure 5). Critical words appeared as the first word of a sentence. Matched sentences consisted of the same number of words. All critical words were used in singular and nominative case, and were matched with respect to gender. All three forms of the definite articles in nominative case, *Der* (masculine), *Die* (feminine), and *Das* (neuter), were used. Critical nouns were taken from the pool of the previous experiments, that is, they

were common four- to six-letter words in German, all beginning with *D* (10 masculine, 4 feminine, and 4 neuter).

Again, each sentence contained two control words, one definite article and one noun. Critical words were never placed at the end of a sentence, and control words were never placed at the beginning or the end of a sentence. Other *d*s in addition to the target *d*s could appear in the sentence but not in the words immediately preceding or following the critical and control words. These *d*s were equally frequent in the matched sentence pairs.

From each of these sentences we derived a second version with the phrase including the critical words appearing now within the sentence. In this version the subject was placed after the verb either by nominating the (prepositional) object phrase first or by changing the sequence of main clause and subordinate clause (see Sentences 3 and 4, and Figure 5 for another example). In this manner we formed 72 sentences, one half with the critical words at the beginning and the other half with the critical words within a sentence.

Two versions of the passage were formed, a normal and a distorted version. In the distorted passage we changed the capitalization of the critical words, such that all critical nouns were uncapitalized whether they appeared at the beginning or within a sentence. Critical articles were printed in lowercase at the beginning of each sentence and capitalized within the sentences. Capitalization of some other words in each sentence was also reversed, but not of the words just before or just after the critical and control words. The number of capitalized words was kept equal across the distorted and the normal versions of each sentence, and the first word of each sentence was always uncapitalized. The capitalization of the control words was never changed, either in the normal or in the distorted passage.

Procedure. Each participant received 36 normal and 36 distorted sentences, one half of them with the critical words at the beginning, and the other half with the critical words within a sentence. The sentences were printed in random order, so that the normal and distorted passages were printed each on two pages. All participants received both the normal and the distorted passage in a counterbalanced order. In all other aspects, the procedure was identical to that of Experiment 1. Additionally, in the case of sentences that began with a critical word, the last word of the preceding sentence never contained a *d*.

Results

Reading times. Reading times per word were significantly longer for the distorted (572 ms, 95% confidence interval between 557 and 587 ms) than for the normal text (540 ms, 95% confidence interval between 525 and 555 ms), $t(31) = 3.26$, $p < .05$. As mentioned above, slower reading speed can be assumed to improve letter detection. Thus, the effects of distortion to be reported below may represent an underestimate.

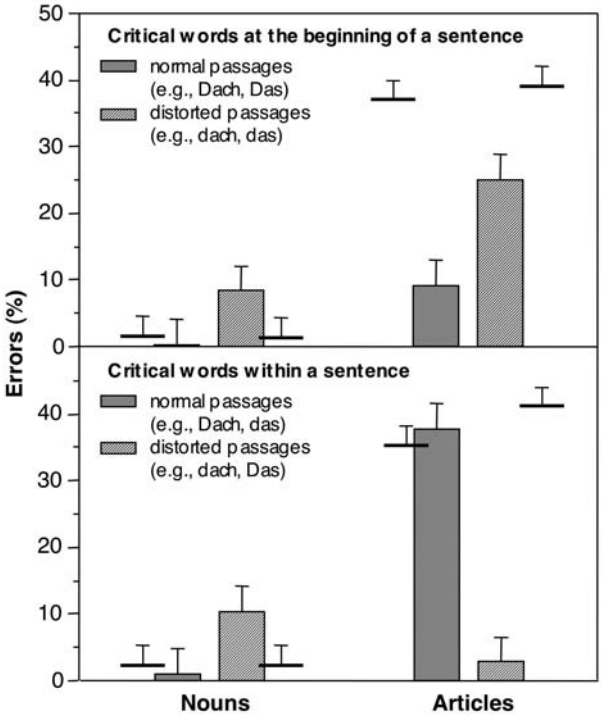

Figure 6. Mean percentages of detection errors for nouns and definite articles appearing at the beginning and within a sentence in Experiment 4.

Letter detection in critical words. Figure 6 shows that at the beginning of a sentence a missing-letter effect was found in normal passages and in distorted passages, although this effect was somewhat smaller in normal passages. In contrast, with the critical words within a sentence, the missing-letter effect was observed only in normal passages, but not in the distorted passages. The latter results replicated the findings of Experiment 1.

A Word Class (nouns vs. articles) x Text Type (normal vs. distorted) x Position (beginning vs. within a sentence) ANOVA on the percentages of omission errors yielded a higher omission rate for definite articles, $F(1, 31) = 31.06$, $MSE = 384.92$, $p < .001$. In addition, the following interactions were significant: Word Class x Text Type, $F(1, 31) = 18.74$, $MSE = 286.44$, $p < .001$, Position x Text Type, $F(1, 31) = 47.43$, $MSE = 206.22$, $p < .001$, and the triple interaction, $F(1, 31) = 58.70$, $MSE = 186.09$, $p < .001$.

A separate Word Class x Text Type ANOVA for critical words at the *beginning* of a sentence yielded significant effects for Word Class, $F(1, 31) = 21.69$, $MSE = 250.12$, $p < .001$, with a higher rate of omission errors for articles (17.4%) than for nouns (4.3%) and for Text Type, $F(1, 31) = 24.33$, $MSE = 177.94$, $p < .001$, with more detection errors in distorted (16.7%) than in normal text (5.0%). The interaction was not significant, $F(1, 31) = 2.79$, $MSE = 152.55$, $p = .105$. Mean error rates for words at the beginning of a sentence are plotted in Figure 6, upper panel.

A comparison of the means for definite articles (9.7%) and nouns (0.3%) in normal text (recall that both were correctly capitalized) at the beginning of a sentence yielded the typical missing-letter effect, $t(31) = 3.61$, $p < .001$, one-tailed, exactly as was found to be the case for the comparison between definite articles (25%) and nouns (8.3%) in the distorted version when both had reversed capitalization, $t(31) = 3.88$, $p < .001$, one-tailed. Nevertheless, changes in capitalization strongly influenced letter detection. At the beginning of a sentence, the rate of omission errors was lower in capitalized articles (9.7%) than in uncapitalized articles (25.0%), $t(31) = 3.75$, $p < .0125$. Furthermore, there was a significant difference between capitalized and noncapitalized nouns, with fewer errors in capitalized nouns, 0.4% versus 8.3%, $t(31) = 3.97$, $p < .0125$. These results suggest a strong influence of capitalization on the rate of omission errors across nouns and articles so that uppercase letters are better detected than lowercase letters. However, the missing-letter effect was nevertheless found for words at the beginning of a sentence despite the changes in visual word shape.

Turning next to the critical words *within a sentence* (see Figure 6, lower panel). A similar two-way ANOVA as above yielded a significant effect for Word Class, with a higher error rate for articles (20.3%) than for nouns (5.7%), $F(1, 31) = 25.94$, $MSE = 262.35$, $p < .001$. The effect of Text Type indicated more errors in normal (19.4%) than in distorted text (2.3%), $F(1, 31) = 26.41$, $MSE = 200$, $p < .001$, and the interaction was also significant, $F(1, 31) = 48.99$, $MSE = 322.58$, $p < .001$. A comparison of means revealed the typical missing-letter effect in normal passages within a sentence, 37.8% versus 1%, respectively, $t(31) = 7.15$, $p < .001$, one-tailed. However, in contrast to the results for critical words at the beginning of a sentence, the missing-letter effect was wiped out in the distorted passages with a tendency for a reversal, 2.8% versus 10.4%, $t(31) = 2.41$, $.0125 < p < .05$. Error rates in nouns differed significantly between normal (capitalized) and distorted (uncapitalized) text, 1% versus 10.4%, respectively, $t(31) = 3.37$, $p < .0125$. However, this pattern of results was reversed for articles: Omission errors for normal (uncapitalized) and distorted (capitalized) articles averaged 37.9% and 2.8%, respectively, $t(31) = 7.03$, $p < .0125$.

Letter detection in control words. Control words were correctly capitalized in both the normal and the distorted text versions. A Word Class x Text Type x Position ANOVA yielded only a highly significant effect for Word Class, $F(1, 31) = 93.45$, $MSE = 898.73$, $p < .001$, with a higher rate of detection errors for articles.

Discussion

We found more errors in normal text for correctly capitalized definite articles than for capitalized nouns at the beginning of a sentence. Although letter detection in general seemed to be better for capitalized letters, we observed also a typical missing-letter effect at the beginning of a sentence in the distorted version, in which all words began with small letters.

It seems that capitalization generally improves letter detection across nouns and definite articles, which might stem from the different visual shape of *D*s and *d*s. Indeed, there is some evidence that uppercase letters are generally better detected than lowercase letters (e.g., McClelland, 1976; Philips, 1979; Sanocki, 1991). Nevertheless, readers seem to distinguish a correct from an incorrect use of capitalized articles. When a capitalized article appeared in a grammatically correct position, a missing-letter effect was observed. However, when they appeared incorrectly within a sentence, the missing-letter effect was completely wiped out, thus replicating the results of Experiment 1.

General Discussion

The present study examined the role of the convention in German to capitalize the initial letters of nouns. Specifically, if the capitalization of the initial letter of nouns serves as a cue for word class, it should affect structural extraction and thereby the missing-letter effect. This question was tested by the capitalization of definite articles and the noncapitalization of nouns (Experiment 1), and by manipulating the position of capitalized articles within a sentence (Experiment 4). In order to discriminate capitalization of nouns from other variations of visual word shape that do not destroy cues for the word class, we also examined the effects of case alternation within nouns and articles (Experiment 2), and of variations in font size (Experiment 3).

The results lend some support to the idea that the German capitalization of nouns is used by readers as a cue for word class, thus affecting letter-detection patterns. In Experiment 1, we used capitalized articles and noncapitalized nouns within a sentence. This manipulation eliminated completely the missing-letter effect. In

contrast, a reduced but reliable missing-letter effect was observed in Experiments 2 and 3, in which the correct capitalization of the first letter was preserved, but visual word shape was impaired by case alternation or font size. Although word shape of definite articles was identical in both conditions of Experiment 4, a missing-letter effect for capitalized articles was observed at the beginning of a sentence, but not within a sentence. This result also demonstrates that capitalization is not only another additive factor that affects the letter detection irrespective of the word's grammatical class.

So far, function words were assumed to form the structure within the punctuation marks of a sentence. The present findings indicate that in German the capitalization of meaning-laden nouns also contributes to the structure. The question is whether establishing the structure based on function words is the same as establishing the structure based on the meaning-laden content words. Note that the capitalization of words is not a reliable marker for content words per se because other content words are not capitalized in German (e.g., adjectives or verbs). This points to a specific role of nouns, maybe when establishing the structure at the phrase level.

In none of the experiments did we find evidence that the effects of the capitalization manipulation generalized to the correctly capitalized control words that were embedded within a distorted passage. The control words yielded an almost typical missing-letter effect under all conditions. Because the capitalization of the words appearing immediately before or after the control words was not changed (as was the capitalization before and after the critical words), the control words were embedded within words of a normal phrase. Additionally, taking into consideration the different detection rates within the distorted phrases, this suggests that the missing-letter effect occurs at the phrase level rather than at the sentence level (but see Müsseler et al., 2000).

Previous studies have examined the effects of several orthographic variations in nouns and articles on the missing-letter effect. Healy and her collaborators (Drewnowski & Healy, 1977, 1982; Healy, 1980; Healy & Drewnowski, 1983) found improved letter detection in *the* when its visual shape was changed by case alternation or misspelling. The present study additionally demonstrates the importance of the first letter of a noun for identifying its word class at an early stage of sentence processing in German. The correct use of German capitalization facilitates the specification of word class before analyzing the meaning of the words, by differentiating nouns and non-nouns at the text surface, that is, before the semantic analysis takes place. In this respect our results are generally in line with the conclusion of Bock (1989; see also Bock et al., 1985) that a capitalized initial letter activates the lexical units of nouns. An irregular capitalization of the initial letter is assumed to initially activate wrong lexical units. Indeed, the missing-letter effect was eliminated in Experiment 1, where we used capitalized articles, which impair the proper class assignment. However, in Experiments 2 and 3, the correct capitalization of the first letter increased the rate of detection errors although word shape was strongly distorted. The reduced missing-letter effect observed in Experiments 2 and 3 might derive from the disruption of unitized visual word shape and from increased processing time, consistent with the unitization view. However, this view cannot explain the variability in the magnitude of the missing-letter effect under different manipulations of the word shape. In particular, the results of Experiment 4 suggest that readers distinguish between the correct use of capitalized articles at the beginning of a sentence (which yielded a missing-letter effect), and the incorrect use of capitalized articles within a sentence (which failed to yield a missing-letter effect).

Altogether, the present results yield partial support to both the unitization account and the structural account of the missing-letter effect (see Greenberg et al., 2004). With regard to the unitization account, the results indicate that orthographic variations that impair whole-word visual shape reduce the magnitude of the missing-letter effect, consistent with the assumption that whole-word access preempts access to constituent letters (Healy, 1980). However, the missing-letter effect was observed even when visual shape was strongly distorted. Furthermore, we demonstrated the presence and absence of the missing-letter effect with words of identical shape (Experiment 4), that is, visual familiarity of a unit is a necessary but not sufficient condition for the missing-letter effect to appear. Thus, the results indicate that in German the identification of word class contributes to the missing-letter effect.

Eye movements might reflect – at least in part – the processing times of words. It is known that function words are often skipped by the eyes (see, e.g., Carpenter & Just, 1983; O'Regan, 1979; Rayner & Pollatsek, 1987) and one might therefore argue that letters in function words are missed more frequently. Hadley and Healy (1991) demonstrated that the high error rates on function words disappeared when the words were presented in the fovea, suggesting that unitization depends on parafoveal identification of familiar words where letter processing is not available (see also Carpenter & Just, 1983; Healy 1994; Koriat & Greenberg, 1996; Rayner & Pollatsek, 1987). Indeed, Saint-Aubin and Klein (2001) partly confirmed this parafoveal-processing hypothesis. They demonstrated

that function words were more likely to be skipped than content words. Nevertheless, they observed a missing-letter effect even if parafoveal processing was prevented, that is, they found a reduced but reliable missing-letter effect also for fixated function words. The decrease of the missing-letter effect is in accordance with the parafoveal-processing hypothesis insofar as the information on the letter level is best in the fovea and less available in the parafovea.

In our view, the skipping of function words with the eyes and the missing-letter effect are two sides of the same coin. Both observations could be seen as a reflection or consequence of the cognitive mechanisms underlying sentence processing (Koriat & Greenberg, 1996). In other words, it is likely that word shape, parafoveal identification, and structural processing are factors responsible for the skipping of function words, which might also contribute to the missing-letter effect. Saint-Aubin and Klein (2001) also favoured such an integrative view (see also Greenberg et al., 2004). According to these authors, familiarity of meaning and visual configuration influences processing time, whereas the coding of structure is aided by familiar phrase structures. The familiarity of the syntactic structure could also allow a faster processing of function words even if they are fixated or their visual word shape is distorted.

To conclude, the study presented here confirms with the letter-detection task that in German the capitalization of nouns is essential for establishing the structural frame of a sentence (cf. Bock, 1989; Bock et al., 1985). This implies that when German readers parse a sentence, they differentiate between the first letter and the remaining letters of the words: Capitalization is critical for the first letter but less critical for the remaining letters. This will allow in future examining another prediction derived from the unitization and the structural view. According to the unitization view, capitalization should equally affect all the letters in the word, while according to the structural view, capitalization should mainly affect the first letters.

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