

Influence of capitalisation and presence of an article in noun phrase recognition in German: Evidence from eye-tracking

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Background: German is exceptional in its use of noun capitalisation. It has been suggested that sentence-internal capitalisation as in German may benefit processing by specifically marking a noun and thus a noun phrase (NP). However, other cues, such as a determiner, can also indicate an NP. The influence of capitalisation on processing may thus be context-dependent, that is, dependent on other cues. Precisely this context dependency is investigated in the current study: Is there an effect of capitalisation on reading and is this affected by the presence of other cues such as a determiner (specifically, an article)?

Methods: We ran an eye-tracking study with 30 German-speaking adults, measuring fixations during sentence reading. Critical NPs either contained correctly capitalised nouns or not and were presented either with or without a determiner.

Results: The results show that both the presence of capitalisation on the noun and the presence of a determiner led to faster reading. When no determiner was present to signal the NP, the presence of noun capitalisation aided reading most.

Conclusions: From these results, we conclude that the influence of capitalisation is indeed context dependent: Capitalisation aids processing most when no other cue is present. Thus, different cues play a role in NP recognition. Based on these findings, we argue that noun capitalisation should not be studied in isolation. We argue that a better understanding of capitalisation as a reading aid is relevant for teaching reading strategies.

Keywords: capitalisation, German, determiner, eye-tracking, head of the noun phrase

Highlights

What is already known about this topic

- German has the quite exceptional characteristic of sentence-internal capitalisation of all nouns.
- The function of sentence-internal capitalisation is controversial.

What this paper adds

- This study experimentally shows that capitalisation and presence of an article conspire in NP recognition in German.
- We find that capitalisation aids processing. This effect is strongest when no determiner is present.

Implications for theory, policy or practice

- We argue that possible reading aids for NP recognition (like capitalisation, articles and adjectives) should not be studied in isolation.
- Investigations of these aids and how they may interact should also be done for other languages.
- A better understanding of capitalisation as a reading aid is relevant for teaching reading strategies.

Capitalisation of the first word of a sentence and of proper nouns is common for languages with the Latin alphabet, but sentence-internal capitalisation of all nouns is unique to languages in the High German family, the best-known example of which is modern-day German. This means there is an alternation of upper and lower case letters, in most languages mainly at the beginning of a sentence and for proper nouns, but in German by default also within the sentence. Since no data exist on how often a German reader in fact encounters sentence-internal capitalisation, we examined the prevalence of sentence-internal capitalisation in German with a small corpus query. This resulted in the following figures (see Appendix A): Over the years 1995–2015, there were between 31.4% and 33.3% capitalised words in news articles (approx. 150,000 tokens per year). This means that (almost) every third word in German texts is capitalised, not taking sentence-initial capitalisation into account.

One can wonder why German has maintained this capitalisation system. It has been argued that sentence-internal capitalisation as in German may benefit processing when reading by specifically signalling a noun phrase (NP) (e.g., Bock et al., 1985, 1989; Pauly & Nottbusch, 2020). This is because the system of sentence-internal capitalisation in German has developed in such a way that the head of the NP is capitalised. Since the beginning of the 20th century, German has seen a shift from lexical capitalisation to syntactic capitalisation (Bredel, 2006). Lexical capitalisation means that for every single word, it can be decided if it is a noun or not. Syntactic capitalisation means that in every context it is checked if the word is the head of an NP or not. Following these rules, the head in

das lyrische Ich ('the lyrical me'), *das schöne Grün* ('the beautiful green') and *das fürchterliche Warten* ('the dreadful waiting') is capitalised and accordingly *er ist pleite* ('he is broke/bankrupt') is written in lower case because *pleite* in the meaning that is used in this sentence cannot be expanded into an NP (\neq *er ist eine (große) Pleite* 'he is a (big) bankrupt'). As a consequence, when reading a text, capitalisation provides a strong cue regarding the syntactic category of the word, namely, it being the head of an NP.

Previous studies have only examined sentence-internal capitalisation of nouns in isolation. Although sentence-internal capitalisation could aid in the identification of an NP, head nouns are often preceded by articles and/or adjectives, and these would provide an earlier cue on the presence of an NP. In this paper, we experimentally test the hypothesis that the effect of capitalisation on reading is influenced by the presence or absence of other cues signalling an NP. We performed an experiment that focuses on the entire NP: Sentences are constructed including a noun both with or without capitalisation and with or without a preceding article – that is, two cues for NPs. We examine whether there is an effect of capitalisation on reading and whether this is affected by the presence of a determiner.

Background

Perception of Noun Capitalisation

It is first important to establish whether capitalisation is perceived relatively effortlessly before we can examine whether it provides any reading or processing benefits. Several studies indeed provide this evidence. Jacobs et al. (2008) presented single German words in three different variations: completely lower case, completely capitalised or with initial capitalisation (i.e., according to the German rules for nouns). Participants were asked to type in the word, which was presented to them for 50 milliseconds. The results showed that regularly spelled nouns were recognised better than the two other versions. Of course, this is in line with the sentence-internal capitalisation rules in German. For non-nouns, on the other hand, it was irrelevant whether the word began with an upper case or a lower case letter.

Funke and Sieger (2009) investigated sentences that were only disambiguated through capitalisation. For example, in sentence (1), the word 'spiele' can be a noun or a verb depending on whether word-initial capitalisation is used (p. 37).

- 1 Beim Sommerfest langweile ich mich nie, weil ich den ganzen Tag über **Spiele/spiele** und Wettkämpfe anschaue.

I never get bored at the summer festival, because ...

Noun interpretation: I watch games and competitions all day.

Verb interpretation: I play and watch competitions all day.

The authors used a question (What is the speaker doing?) to probe whether participants perceived the spelling of the critical word (i.e., are they watching games or playing?). In short, the results showed that participants used upper and lower case to ascribe syntactic structure. Together, these studies confirm an important premise of the current study: Sentence-internal noun capitalisation is well perceived and used in processing.

Effects of Noun Capitalisation

Various psycholinguistic experiments investigating the potential benefits of sentence-internal capitalisation have been carried out (Bock et al., 1989; Cutter et al., 2020; Gfroerer et al., 1989; Hohenstein & Kliegl, 2013; Pauly & Nottbusch, 2016, 2020). The experiments by Bock and colleagues have recently received some criticism, and better techniques have been developed since the late 1980s. Nevertheless, they provide some interesting and relevant findings.

Bock et al. (1989) measured the reading time of German, English and Dutch texts in two groups of participants: Dutch and German were read by Dutch readers, and German and English by German readers. The texts were manipulated in several ways, the most relevant of which are regular capitalisation according to German rules (i.e., capitalised nouns and capitalised sentence-initial words) and moderate lower case (according to Dutch and English rules, i.e., capitalised sentence-initial words and proper names, but other nouns not capitalised). Roughly, the findings showed that German participants read texts with regular German capitalisation faster than other manipulations. For the Dutch participants, German-style capitalisation helped in German but not in Dutch texts: Dutch texts with Dutch capitalisation rules were read fastest. However, there was some positive effect of noun capitalisation on reading times, as this condition was read faster than when all words were capitalised. Based on this, Bock et al. (1989) conclude that capitalisation is an independent function that could, in principle, be transferred onto another languages. In contrast, Gfroerer et al. (1989), who repeated the experiment of Bock et al. (1989) but additionally measured eye movements, surprisingly found that Dutch readers who are also fluent in reading German read Dutch texts with German-style capitalisation more quickly than with regular, Dutch-style capitalisation. Although these results provide interesting initial indications of the effect of capitalisation, arguably they cannot offer more than that. This was a relatively small study with a small group of subjects ($n = 22$) who – presumably for technical reasons – show a great deal of variance in the data. In a recent eye-tracking pilot study, Van Rijn and Vogelzang (2019) attempted to replicate the findings of Gfroerer et al. (1989), but they found a slowdown instead of a speed-up when Dutch readers were presented with German-style capitalisation in Dutch texts. In line with these mixed results, after reviewing the literature, Müller (2016) concluded that there is no clear influence of capitalisation on reading speed.

However, recent studies have provided some evidence for the use of capitalisation in reading. Evidence regarding the effects of the recognition of capitalised words in the semantic field comes from research on the ‘semantic preview benefit’. This effect occurs when semantic information is obtained from the word succeeding the word that is currently fixated. Such semantic preview benefits have been observed with nouns in German (both when noun capitalisation was present and when it was not; Hohenstein & Kliegl, 2014) and also in English, but importantly they only seem to occur in English when the noun is capitalised (Rayner & Schotter, 2014). A recent study found that capitalisation is not only used to obtain early semantic information (Rayner & Schotter, 2014) but also to infer syntactic category (Cutter et al., 2020). Specifically, Cutter et al. found that proper noun capitalisation in English led to differences between the reading of subject relative clauses (*The tall lanky guard who alerted Charlie to the danger was young*) and object relative clauses (*The tall lanky guard who Charlie alerted to the danger was young*). Fixations were longer for the syntactically more complex object relative sentences before the words in these two sentence types started to differ, namely, on the relative pronoun ‘who’ (Cutter

et al., 2020, p. 1150). This suggests that parafoveal preview picks up the capitalisation of the upcoming word and that this helps in processing the syntactic class of that word. In addition, on the relative clauses themselves, they observed longer reading times in object relative clauses compared to subject relative clauses when all caps was used (and thus when capitalisation did not provide a useful cue), but this effect disappeared when only the proper noun (*Charlie*) was capitalised, indicating that capitalisation does provide some benefit to reading.

Effects of Noun Capitalisation in Context

In an eye-tracking study, Pauly and Nottbusch (2016, 2020) used semantic priming to build up expectations about an upcoming noun. In reality, however, this upcoming word was an attribute of the succeeding noun. Specifically, they examined adjective + noun combinations in sentences with garden path ambiguities like (2b) compared to (2a).

- 2a. In der Gymnastikhalle liegen die matten Sportler auf dem Boden.
- 2b. In der gymnastikhalle liegen die matten sportler auf dem boden.

In the gymnastics hall, the tired athletes lie on the floor.

The ambiguity here is due to the word *matten*, which could be an adjective ('tired') or a noun ('mats', but in that case it would need capitalisation). *Gymnastikhalle* is used to prime *matten* as a noun. When the sentence uses no capitalisation (2b) and the actual head of the NP ('Sportler') is thus also not capitalised, this is expected to lead to a garden path interpretation of *matten*. These sentences were contrasted with sentences in which the adjective cannot serve as a noun (such as *steten* 'steady') and could thus not lead to a garden path, such as in (3).

- 3a. In der Gymnastikhalle liegen die steten Sportler auf dem Boden.
- 3b. In der gymnastikhalle liegen die steten sportler auf dem boden.

In the gymnastics hall, the 'steady' athletes lie on the floor.

Pauly and Nottbusch predicted that if capitalisation of the noun was processed in advance as a cue, it would prevent the incorrect, garden path parse. In line with previous research, they found that noun capitalisation violations in general slowdown reading, although the effects were small. In contrast, they did not find the expected effect of garden path processing. Finally, some indications were found that the reading of the adjective could be influenced by the capitalisation of the succeeding noun, but only in specific cases (highly frequent noun, non-peculiar adjective), and again with small effects.

Although an interesting first step into the detailed investigation of noun capitalisation in context, the Pauly and Nottbusch (2016, 2020) study has a number of drawbacks. First of all, all NPs included an article (i.e., *die matten* or *die matten Sportler*). So, a potential cue for the presence of an NP (the article *die*) was given in all sentences. In addition, their garden path manipulation did not have the desired effect, and potentially ambiguous sentences such as in (2) were even read faster than the non-ambiguous sentences such as (3). They admit that there were problems with both the garden path and control sentences, partly

due to their semantic oddity. Concluding, the experiment had several methodological issues, and the effects of capitalisation were weak.

An alternative explanation for the effect of noun capitalisation is provided by Hohenstein and Kliegl (2013). They also manipulated capitalisation, but rather than an overall slowdown in reading due to capitalisation violations, they argue that, even though slowdown effects may be found on uncapitalised noun, capitalisation violations influence reading strategy rather than overall reading time. That is, overall reading speed was not affected by the absence of noun capitalisation: Although when nouns were capitalised they were fixated shorter than non-nouns, this effect was reversed for the word preceding the noun. Importantly, in their discussion, they suggest that these parafoveal effects indicate that a noun may already be processed when fixating on the preceding word (Hohenstein & Kliegl, 2013, with reference to the word-group hypothesis of Kliegl, 2007 and Radach, 1996), leading to a slowdown in reading on the word preceding the noun when noun capitalisation is detected.

In summary, if we take the idea of capitalisation marking the head of an NP seriously (Eisenberg, 1981; Maas, 1992¹), then it is surprising that previous experiments have often examined nouns in isolation rather than within the context of the entire NP. Some experiments with ambiguities have been carried out, but the resolution of ambiguities is not the function of capitalisation (Funke & Sieger, 2009). Rather, noun capitalisation is argued to aid the recognition of syntactic structures. To the best of our knowledge, only Van Rijn and Vogelzang (2019) have previously examined the role of the determiner in capitalisation, although not in German: German-style noun capitalisation in Dutch texts slowed down reading, but this effect was decreased when a determiner preceded the noun. We aim to fill this gap in the literature by examining the effects of capitalisation in unambiguous small NPs, namely, those consisting of a determiner and a noun.

We will measure the reading times of the noun, the preceding word and the succeeding word by means of fixations through eye-tracking. Our hypotheses are as follows. We firstly predict, in line with previous studies, that capitalisation violations (i.e., the absence of German-style, sentence-internal noun capitalisation) will lead to a slowdown in reading. Secondly, we predict that this slowdown is reduced by the presence of a determiner, which also signals an NP, so that the effects of capitalisation in German are context dependent.

Methods

Participants

Thirty-four students from the University of Oldenburg, Germany, participated in the experiment for monetary compensation. Four participants were removed from the data set because the eye-tracker had technical difficulties tracking their eyes. Thus, 30 participants remained for analysis (7 men, 23 women; mean age 23.5; age range [18,30]); all were native monolingual speakers of German and had normal or corrected-to-normal vision. The participants reported having no reading or writing disorders. All participants signed an informed consent.

Materials

The experiment used 80 German experimental sentences consisting of two clauses each: a critical main clause and a dependent clause. All sentences were structured around a critical NP in the first clause, which had the structure.

[Adverb] [modal verb] [pronoun] [determiner/Ø] [noun/Noun] [verb]

We used this structure with the pronoun *sie* (they) before the NP in order to have a word of similar length and form directly before the noun in both conditions with and without a determiner (*die* vs. *sie*). In total, 20 different critical nouns were used. Sentences containing these critical nouns were manipulated into four versions using two variables: Capitalisation (whether the noun was capitalised or not) and Determiner (whether a determiner preceded the critical noun or not). Only mass and plural nouns were used as critical nouns, as these can occur both with and without a determiner. All critical nouns were disyllabic and consisted of five to seven letters. In experimental sentences without capitalisation, the noun in the dependent clause was presented without capitalisation as well. Examples of an experimental item in all four manipulations are shown in Table 1.² For all versions of one experimental item, the main clause remained constant and varied only on the basis of the experimental manipulations. The dependent clause that succeeded a critical main clause varied for every sentence manipulation.

Besides experimental sentences, 40 control and 120 filler sentences were included. In control sentences, an adverb was either (incorrectly) capitalised or not. The filler sentences contained various other capitalisation violations to distract from the purpose of the experiment.

There were a total of 240 sentences in the experiment (80 experimental sentences, 160 control and filler sentences). The experiment was divided into two test sessions, conducted on different days, with 120 sentences in each session. Each session consisted of two blocks of 60 sentences, with a break in between. Each block contained 20 experimental sentences (five in each of the four conditions) and 40 control and filler sentences. Note that participants were tested on all four manipulations of an experimental item over the course of the experiment, but saw only one manipulation of each item within each block, and thus

Table 1. Example experimental item in German (with English glosses) in the four different manipulations used in the experiment.

Cap	Det	Critical main clause	Dependent clause
+	+	Morgen wollten sie <i>die</i> Kerzen herstellen, <i>Tomorrow wanted they the Candles make,</i>	obwohl ihnen dazu noch die Dochte fehlten. <i>although to-them for-that still the Wicks lacked.</i>
+	–	Morgen wollten sie Kerzen herstellen, <i>Tomorrow wanted they Candles make,</i>	obwohl es im Sommer auch nachts noch warm war. <i>although it in Summer also at-night still warm was.</i>
–	+	Morgen wollten sie <i>die</i> kerzen herstellen, <i>Tomorrow wanted they the candles make,</i>	obwohl sie nicht viel frisches wachs hatten. <i>although they not much fresh wax had.</i>
–	–	Morgen wollten sie kerzen herstellen, <i>Tomorrow wanted they candles make,</i>	obwohl sie schon elektrisches licht hatten. <i>although they already electric light had.</i>

Cap, Capitalisation; Det, Determiner.

The critical noun in each sentence is written in bold, the determiner (when present) in italics.

only two manipulations of each item in one session on 1 day. This design was chosen to obtain the maximal amount of comparable, within-subject data points. Two pseudo-randomised lists were created for each session that were used both in their original order and in reverse order. Combining the test lists for both sessions resulted in a total of eight different list combinations.

Procedure

The experiment was carried out in the Speech and Music Lab at the University of Oldenburg, Germany. Participants were instructed to read the sentences carefully and judge whether they were meaningful. An Eyelink Portable Duo eye-tracker recorded their eye movements.

After a training phase with five sentences, the eye-tracker was calibrated with a 9-point calibration. A drift correction was carried out before each sentence. Each sentence was presented on the screen on a single line. After reading a sentence, the participants could continue with a mouse click. Participants were then asked to rate the meaningfulness of the sentence on a scale from 1 (*sehr sinnvoll*, ‘very meaningful’) to 6 (*sehr sinnlos*, ‘very meaningless’). This task was introduced to ensure that participants read the sentences attentively. All experimental and control items were intended to be meaningful; 75 of the fillers were intended to not be meaningful.

The participants were tested in two sessions on different days. The average total duration of the two sessions together was 90 minutes. The study was conducted in accordance with the Declaration of Helsinki.

Data Processing and Analysis

Fixations were automatically detected by the Eyelink software. The data were pre-processed per trial and per participant. Trials (sentences) with fewer than seven fixations were removed (1.5% of the data). Fixations of less than 80 milliseconds were merged with nearby fixations (within a distance of 35 pixels). Finally, remaining fixations shorter than 60 ms were removed (in line with Rayner et al., 2012, p. 132).

In order to analyse the fixations on the relevant words, areas of interest (AOIs) were defined. The height of the AOIs was two lines below and above the text, the width was determined by the word length, and boundaries were in the middle between two words. The AOIs used for analysis were the word preceding the critical noun (to examine parafoveal effects; Cutter et al., 2020; Hohenstein & Kliegl, 2013), the critical noun, the succeeding verb (spillover region) and the critical noun + the spillover region in the main clause. Following Cutter et al. (2020), who addressed a similar research question, we examine several measures of reading behaviour in these regions: (1) First Fixation Duration (FFD, i.e., the duration of the first fixation on the AOI), (2) First Pass Duration (FPD, i.e., the sum of all fixations from the first fixation on an AOI until exiting the AOI), (3) Go-Past Time (GPT, i.e., the sum of all fixations from the first fixation on an AOI until fixating on a subsequent AOI), (4) Total Reading Time (TRT, i.e., the sum of all fixations on an AOI) and (5) Skipping Probability (SP, i.e., the probability of skipping an AOI in the first pass reading).

These different measures of reading behaviour were analysed with (generalised) linear mixed-effects models in R using the *lme4* package (Bates et al., 2015). Log-transformed values of the reading behaviour measures or binary values of skipping probability were entered as the dependent variable. Based on the hypotheses, we used nested models to

examine the effects of Determiner (fixed factor) and the nested effects of Capitalisation within each level of Determiner, thus estimating the effect of Capitalisation separately for sentences with and without a determiner. These nested effects (Schad et al., 2020; for other applications of such models, see Fühner et al., 2021; Schad et al., 2010) fit the hypotheses of differential effects of capitalisation with and without a determiner present and remove the need for follow-up comparisons. Random intercepts for participant and item were included when possible (i.e., when these allowed for model convergence). The covariate of sequential trial number was included as a simple effect or as an interaction with Determiner or Capitalisation only when model comparisons based on the Bayesian Information Criterion indicated that inclusion was justified. Note that sequential trial number never interacted with the critical effects of Determiner or Capitalisation. Deviation (sum) contrast coding (-0.5 and 0.5) was used for the factors of Determiner and Capitalisation. Capitalisation and the presence of a determiner were coded as the reference levels. The reported p -values have not been corrected for multiple comparisons. When a Bonferroni correction is applied, by correcting the original significance threshold ($\alpha_{\text{original}} = 0.05$) for the number of comparisons for each AOI (5), the corrected significance threshold is ($\alpha_{\text{corrected}} = 0.05/5$) 0.01.

Results

The results of the different measures of reading time are presented in Table 2. The results of the linear mixed-effects model analyses are presented in Table 3.

The *pre-critical region* consisted of a determiner (*die*) when a determiner was present but of a pronoun (*sie*) when no determiner was present in the sentence manipulation. The model results (Table 3, top row) only show an effect of capitalisation in the FPD in sentences with a determiner. That is, there was a slowdown in reading the determiner ($273-254 = 19$ ms) when capitalisation was absent. This may suggest that parafoveal preview effects are at play and the capitalisation violation was already detected at the determiner (but not at the pronoun). However, because the other measures of reading behaviour did not show similar effects, and the p -value for this effect does not survive Bonferroni corrections for multiple comparisons, this finding should be interpreted with caution. In contrast, effects of determiner presence, that is, comparing reading the determiner *die* with reading the pronoun *sie*, were found in four out of five reading measures (FPD, GPT, TRT, SP – the effects in GPT and SP persist after Bonferroni corrections). All effects indicated that pronouns were read faster (and skipped more) than determiners when directly preceding the critical noun, regardless of capitalisation of this noun. These words have the same word length, but differ in word category and grammatical function. Specifically, *sie* is the pronominal subject of the sentence and *die* an article in the NP, which will make up the object. Thus, one explanation could be that subjects are read faster than objects. A more likely explanation, however, is that participants are starting to (syntactically) process the larger NP already when encountering the determiner, which is reflected in somewhat slower reading. These explanations are difficult to distinguish based on the data from the pre-critical region, so we turn to the critical region next.

In the *critical region*, both effects of determiner and effects of capitalisation when a determiner is absent were found (Table 3, second row). Turning to the first effect, this shows that participants skipped over the critical noun more frequently when it followed a determiner. Potentially, the presence of an NP has already been detected when reading the

Table 2. Overview of the means (and standard errors) for the reading behaviour measures (times in ms, SP in percentages) in the four different areas of interest in each condition.

	+Determiner		–Determiner	
	+Capitalisation	–Capitalisation	+Capitalisation	–Capitalisation
Pre-critical region ^a				
FFD	210 (4.2)	215 (4.3)	218 (4.3)	217 (4.5)
FPD	254 (7.6)	273 (7.2)	250 (7.0)	242 (5.9)
GPT	282 (8.6)	291 (8.0)	268 (7.2)	261 (6.7)
TRT	319 (10.9)	326 (9.9)	298 (8.4)	297 (9.2)
SP	23 (1.7)	24 (1.8)	27 (1.8)	28 (1.8)
Critical region				
FFD	214 (4.1)	220 (4.2)	207 (3.7)	218 (3.9)
FPD	276 (7.7)	286 (8.0)	281 (7.9)	284 (8.5)
GPT	297 (8.7)	310 (9.1)	305 (9.0)	310 (9.5)
TRT	343 (11.3)	345 (11.5)	356 (11.0)	354 (11.6)
SP	27 (1.8)	25 (1.8)	22 (1.7)	16 (1.5)
Spillover region				
FFD	216 (4.3)	220 (4.3)	216 (3.9)	212 (3.7)
FPD	290 (7.8)	296 (7.8)	294 (7.8)	300 (7.9)
GPT	314 (9.7)	323 (9.2)	313 (8.4)	337 (9.5)
TRT	356 (12.4)	247 (10.1)	347 (10.1)	369 (11.2)
SP	20 (1.6)	18 (1.6)	22 (1.7)	18 (1.6)
Critical + spillover region				
FFD	344 (6.4)	364 (6.6)	345 (6.2)	367 (6.0)
FPD	453 (9.1)	481 (10.1)	469 (9.6)	499 (10.8)
GPT	489 (11.4)	523 (11.8)	503 (10.9)	553 (12.3)
TRT	559 (15.8)	571 (13.8)	573 (14.2)	618 (15.7)
SP	4 (0.8)	4 (0.8)	4 (0.8)	3 (0.7)

FFD, First Fixation Duration; FPD, First Pass Duration; GPT, Go-Past Time; SP, Skipping Probability; TRT, Total Reading Time.

^aThe pre-critical region was a determiner (*die*) when a determiner was present and a pronoun (*sie*) when no determiner was present. The critical region was always the noun, and the spillover region was always the verb following the noun.

determiner. In addition, effects of capitalisation were found (FFD, SP) in sentences without a determiner but not in sentences with a determiner. Thus, in sentences with a determiner, noun capitalisation does not seem to affect noun reading. In contrast, in sentences without a determiner, noun capitalisation speeds up noun reading (FFD: 218–207 = 11 ms; note that this effect does not survive Bonferroni corrections) and increases skipping probability (22–16 = 6%). These results support the idea that violations in noun capitalisation are detected and that capitalisation can aid processing when no determiner is present.

In the *spillover region* (Table 3, third row), no significant effects were found. In the final AOI, that of *the critical noun + spillover region* (Table 3, bottom row), several effects were

Table 3. Overview of the linear mixed-effects models' output in the four different areas of interest for the different measures. Nested effects of Capitalisation in sentences with and without a determiner were obtained. Capitalisation and the presence of a determiner were coded as the reference levels.

	Determiner			Capitalisation effect with a determiner			Capitalisation effect without a determiner		
	β	t/z	p	β	t/z	p	β	t/z	p
Pre-critical region									
FFD	.022	1.213	.225	.025	0.995	.320	-.011	-0.408	.683
FPD	-.049	-2.225	.026*	.079	2.574	.010*	-.019	-0.592	.554
GPT	-.061	-2.645	.008**	.046	1.423	.155	-.020	-0.591	.554
TRT	-.062	-2.443	.015*	.052	1.486	.137	-.018	-0.506	.613
SP	.253	2.594	.009**	.090	0.635	.526	.014	0.105	.917
Critical region									
FFD ^a	-.025	-0.977	.327	.047	1.875	.061	.079	1.972	.048*
FPD	-.004	-0.181	.856	.040	1.181	.238	.022	0.678	.498
GPT	.006	0.262	.793	.045	1.276	.202	.035	1.035	.301
TRT	.026	0.981	.327	.008	0.214	.831	.004	0.108	.914
SP	-.417	-4.067	<.001***	-.132	-0.965	.334	-.395	-2.577	.009**
Spillover region									
FFD	-.015	-0.859	.390	.022	0.897	.370	-.022	-0.903	.367
FPD	.017	0.746	.455	.020	0.649	.517	.017	0.521	.603
GPT	.032	1.396	.163	.031	0.936	.350	.058	1.742	.082
TRT	.034	1.364	.173	-.001	-0.012	.990	.057	1.623	.105
SP	.080	0.734	.463	-.153	-0.990	.322	-.271	-1.782	.075
Critical + spillover region									
FFD	.020	1.133	.257	.061	2.383	.017*	.072	2.802	.005**
FPD	.038	1.902	.057	.048	1.703	.089	.070	2.491	.013*
GPT	.053	2.606	.009**	.065	2.246	.025*	.102	3.531	<.001***
TRT	.063	2.809	.005**	.041	1.309	.191	.090	2.845	.004**
SP	-.183	-0.826	.409	.087	0.294	.769	-.417	-1.275	.202

FFD, First Fixation Duration; FPD, First Pass Duration; GPT, Go-Past Time; SP, Skipping Probability; TRT, Total Reading Time.

^aOne of the reviewers raised concerns about the influence of launch site, as parafoveal preview effects could influence the reading times on the critical noun. We therefore checked launch site for warranted inclusion as a covariate and as an interaction in the model for First Fixation Duration on the critical region. The simple effect of launch site contributed to the model, but the interaction did not. The inclusion of launch site did not affect the significance of any of the other effects.

found. Firstly, effects of determiner (GPT, TRT) indicate longer reading times for this region in sentences without a determiner compared to sentences with a determiner. Thus, the presence of a determiner influences the reading of succeeding regions in that it makes their reading faster. Secondly, in sentences with a determiner, the noun + spillover regions with capitalisation were seemingly read faster than the same regions without capitalisation (FFD: 364–344 = 20 ms, GPT: 523–489 = 34 ms). However, these effects do not survive

Bonferroni corrections. Finally, in sentences without a determiner, effects of capitalisation were found in four out of five reading measures (FFD, FPD, GPT, TRT – all but FPD persist after Bonferroni corrections): Correct noun capitalisation increased reading speed when no determiner was present to signal the upcoming NP (FFD: 367–345 = 22 ms, FPD: 499–469 = 30 ms, GPT: 553–503 = 50 ms, TRT: 618–573 = 45 ms).

Discussion

When we assume that noun capitalisation serves to identify the head of an NP, capitalisation should not be investigated on nouns in isolation, but within the context of an NP, for example, with a determiner or an adjective. The experimental results presented in this paper show effects of the presence of a determiner on the effects of capitalisation in a very simple NP (determiner and noun), which supports our idea that the effect of capitalisation depends on the presence of other cues that make up the NP. Specifically, evidence was found that the presence of a determiner makes a succeeding noun more likely to be skipped, or, conversely that the absence of a determiner necessitates a fixation on the noun. Furthermore, we found effects of the presence of capitalisation, especially in sentences without a determiner. We interpret these results as providing support for the idea that violations in noun capitalisation can hinder reading when no determiner is present, or, conversely, that noun capitalisation aids reading. It is important to note that slowed-down reading as an effect of a noun capitalisation violation was found both in sentences with and without a determiner – although these did not always survive our stricter criteria for significance. However, it does seem that orthographic violations were detected – as expected – and hindered reading. Nevertheless, when no determiner was present to signal an upcoming NP, capitalisation violations hindered reading more severely. These results show that these two types of cue should not be examined independent from each other, as has been done in previous research.

Before discussing the results in more detail, we would like to address a few possible limitations of our study. Firstly, the pre-critical region, in which a (subject) pronoun was compared to a(n) (object) determiner makes for a skewed comparison, hence we avoid drawing any strong conclusions from the results obtained in this region. Secondly, these words (*sie* and *die*) are both relatively short, which may have affected skipping rates in the pre-critical region. Subsequently, this may have affected potential parafoveal preview effects – of which some evidence was nevertheless found – and created differences between the different determiner conditions. A longer word preceding the determiner could have more reliably ensured that the pre-critical region was fixated on. However, this would have made the pre-critical region comparison impossible, which is why we choose to use the short pronoun *sie*. Thirdly, in this experimental design, readers were exposed to a large number of capitalisation errors (in critical, control and filler sentences). Participants could have adapted their reading behaviour to this, leading to smaller effects of capitalisation. Nevertheless, we found no evidence that participants adapted to the capitalisation violations over the time course of the experiment, as indicated by the lack of effects of the sequential trial number factor. Finally, the results obtained are specific to German, as this language uses sentence-internal noun capitalisation. Further investigations of the interplay of different reading aids could be done in other languages, without focusing on capitalisation (rather looking at determiners, adjectives, etc.).

The general slowdown in reading found when noun capitalisation is absent is in line with previous literature (e.g., Pauly & Nottbusch, 2016, 2020). Importantly however, in our experiment the slowdown is strongest for absence of capitalisation in isolation, not in combination with other information (here: presence of an article). Our results suggest that capitalisation is indeed a support for reading processes, which, so far has not been shown clearly in the literature. Throughout this paper, we have worked under the assumption that capitalisation marks the (head of the) NP and as such supports syntactic processing specifically (see footnote 1). This proposition seems to be supported by recent research on English capitalisation using proper names as well (Cutter et al., 2020). Additionally, in line with the results of Cutter et al. (2020), we found some indications of a parafoveal preview effect. Specifically, the violation in capitalisation may have already been detected at the determiner, as reflected by slowed-down reading in that pre-critical region already. We repeat our statement from the introduction that this suggests that parafoveal information picks up the capitalisation and that it helps in processing the syntactic class of that word.

Notably, the idea of noun capitalisation functioning as a reading aid to signal an upcoming noun is slightly different from the idea that nouns are already (partly) processed during fixation on the preceding region, as suggested by Hohenstein and Kliegl (2013). In a simple det + N phrase, we argue that the upcoming noun is predicted and therefore capitalisation on the noun is no longer required to recognise the noun as head of the NP. Since we did not find a slowdown on the determiner when capitalisation was present (contrary to Hohenstein & Kliegl, 2013, in fact, we found some evidence for the opposite effect, i.e., a slowdown on the determiner when capitalisation was absent) and in contrast found effects of capitalisation when no determiner was present, our results do not seem to support Hohenstein and Kliegl's (2013) proposal. Rather, we argue that our results are in line with the idea that the determiner signals an upcoming noun and thus aids the syntactic processing of the NP, even without having seen the upcoming noun in parafoveal preview. However, Hohenstein and Kliegl's (2013) ideas are not in direct contrast with the ideas set forth in the current article.

It remains to be seen what exactly the locus of the benefit of cues signalling an upcoming NP is. It could be the case that such cues allow for the predictive building of upcoming syntactic structures (like in predictive parsing; Demberg et al., 2013; Gibson, 1998; Staub & Clifton, 2006). In addition, if the syntactic category has been predicted, this could facilitate lexical retrieval as well. However, the distinction between such facilitatory effects was not examined in the current study and thus remains open for future investigations.

One could wonder why, if noun capitalisation indeed aids syntactic processing in German, is the head of the NP capitalised rather than another structure? One argument, as we summarised in the Introduction, is that noun capitalisation is a frequent cue: Nearly every third word in German texts is capitalised. In addition, German NPs are potentially long and continuous; in most cases, they are not interrupted by units that do not belong to the phrase, and a 'linear' designation is possible (starting with the article, ending with the capitalised noun). In most cases, capitalisation should appear at the right edge of an NP. Discontinuous NPs are the exception – also in German. A short and simple NP, for example, consisting of det + N, as tested in our experiment, is recognisable as an NP based both on the determiner and on the capitalised noun. If both truly serve as a cue for identification of the NP, then what would happen in longer, more complex NPs? German in particular is known for the possibility of having long and complex NPs. We hypothesise that if sentence-internal capitalisation supports the reading process, then probably more so, the more complex the NP is: With the help of the article the beginning of the NP is marked,

with the help of noun capitalisation the end. This could be investigated experimentally, with a study comparable to ours.

In addition, based on the results from our experiment, we predict that other cues can signal an NP, such as an adjective, and thus support reading processes. Arguably, adjectives might even provide a more reliable cue than articles in German, as the German articles *der*, *die*, *das*, *den*, etc. ('the') do not appear exclusively as articles, but also as demonstrative or relative pronouns. As such, when encountering one of these forms, one cannot be sure that a lexical noun is coming up to form an NP,³ whereas an inflected adjective unambiguously indicates a noun as head of the NP is coming up. Although this may seem trivial, it indicates that there are different potential cues signalling an NP, and it is thus far unknown whether and how these interact during reading.

One could argue that, in some sentence structures, NPs are already signalled by other elements preceding the NP, for example, by the syntax of the verb. However, NPs can occupy multiple syntactic positions: They can be subjects or objects, they can be in prepositional phrases or can themselves be subordinate to an NP in the form of attributes. Furthermore, the syntactic positions filled with a full NP can also always be occupied by a pronoun. Therefore, predicting an upcoming (lexical) NP based on the surrounding syntax (and semantics) may not always be reliably possible. Nevertheless, we assume that sentence structure may also play some role in the 'value' of the cue of capitalisation for signalling an NP. Capitalisation, we argue, is redundant information in the sense that it is not necessary for establishing what is a noun, but it does help in establishing this a little faster.

In conclusion, we found experimental evidence that, in German, both the presence of capitalisation on the noun and the presence of a determiner lead to faster reading. When no determiner was present to signal the NP, the presence of noun capitalisation seems to aid reading most. Thus, noun capitalisation supports reading processes, but its influence is dependent on the preceding context, showing that noun capitalisation should not be studied in isolation. This is potentially relevant for teaching reading strategies: Capitalisation functions as a reading aid, but this effect seems to be context dependent. Follow-up research is needed to examine to what extent capitalisation in combination with other information can be effectively used in reading education.

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Conflict of Interest

The authors declare no competing interests.

Data Availability Statement

The data that support the findings of this study are available from the last author upon reasonable request. The experimental materials are available at https://osf.io/wc6up/?view_only=cb2b44ddc96343bb81547b6e2bb7e1cb.

Endnotes

¹Note that in certain syntactic models, it is argued that noun phrases are part of a determiner phrase and that a determiner is the head of this determiner phrase (DP-analysis; Abney, 1987) and the noun phrase is a complement of this determiner. This analysis would not alter our argumentation though, since in this analysis too, the noun would head the noun phrase within the DP. In fact, the analysis would fit our argumentation quite well, since if the DP has a determiner (in our case an article), this determiner would give the first indication that a DP, and hence a noun phrase is coming up. When the determiner is not realised, as in a determiner-less noun phrase as tested here, the head would remain empty, and only the noun (or alternatively other information like an adjective) will indicate that a DP has to be assumed.

²The full list of the experimental materials can be found at https://osf.io/wc6up/?view_only=cb2b44ddc96343bb81547b6e2bb7e1cb.

³Note that in our experiment these forms were only used as articles and hence were clear cues for the upcoming NP. A study that includes (much) more distractor sentences with demonstrative and relative pronouns would therefore be very useful future research.

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Appendix A

Sentence-internal capitalisation in German (from <http://wortschatz.uni-leipzig.de/en/download/>, Goldhahn et al., 2012, accessed on 08/09/2018). Sentence-initial words were not taken into account.

	Year						
	1995	1996	1997	1998	1999 ^a	2001	2002
Capitalised words	482,047	473,979	460,173	470,211	467,912	465,357	472,351
Words	1,508,591	1,486,426	1,447,675	1,461,689	1,466,695	1,480,160	1,484,546
Percent capitalised	31.95%	31.89%	31.79%	32.17%	31.90%	31.44%	31.82%
	2003	2004	2005	2006	2007	2008	2009
Capitalised words	458,118	466,407	478,214	487,325	455,328	482,826	475,541
Words	1,456,187	1,445,533	1,467,336	1,477,100	1,444,291	1,451,852	1,440,912
Percent capitalised	31.46%	32.27%	32.59%	32.99%	31.53%	33.26%	33.00%
	2010	2011	2012	2013	2014	2015	
Capitalised words	490,962	446,393	478,309	445,379	487,667	484,152	
Words	1,479,354	1,415,076	1,470,187	1,412,330	1,463,546	1,456,048	
Percent capitalised	33.19%	31.55%	32.53%	31.54%	33.32%	33.25%	

^aThe year 2000 is missing in the underlying corpus.

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