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Does the frequency of the antecedent noun affect the resolution of pronominal anaphors? An ERP study

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Abstract

Behavioral studies investigating the influence of the relative word frequency of antecedent nouns on the processing of anaphoric pronouns have yielded contradictory results. While some researchers found no effect of an antecedent's frequency of occurrence on coreference resolution [J. Simner, R. Smyth, Phonological activation in anaphoric lexical access (ALA), Brain Lang. 68 (1999) 40–45], others report shorter reading times for pronouns referring to low compared to high frequency nouns [R.G.P. van Gompel, A. Majid, Antecedent frequency effects during the processing of pronouns, Cognition 90 (2004) 255–264]. Using event-related potentials, our study aimed to further investigate the issue. Participants were presented with sentence pairs, of which the first contained either a high frequency, a middle frequency or a low frequency noun. The second sentence contained a pronoun which referred back to the noun in the first sentence. ERP waves were determined, time-locked to both the nouns and the anaphoric pronouns. We observed a graded N400 effect for antecedents of the three frequency classes with amplitudes reversely related to the word's lexical frequency. Coreferential pronouns elicited a P300, with amplitudes dependent on the noun's relative frequency of occurrence, i.e. the lower the antecedent's word frequency, the higher was the amplitude of the P300. This amplitude effect at the pronoun is interpreted in terms of the allocation of attentional resources to salient discourse entities.

Keywords: Pronouns; Word frequency; Salience; Event-related potentials (ERP); N400; P300

A central aspect of understanding discourse is keeping track of *who* and *what* written or spoken utterances *refer to*. In this sense, referential coherence is crucial to building a mental representation of what a given text is about. Coreferential expressions such as personal or reflexive pronouns are among the most important cohesive ties in language which allow complex ideas to be expressed coherently.

In linguistics, the term *coreference* is used to denote a relationship between two linguistic entities in a given discourse context, e.g. a noun (antecedent) and a pronoun (anaphor) which both refer to one single extra-linguistic entity. Typically, the anaphor is referentially dependent on the antecedent and can only be interpreted properly by taking into account the meaning of the antecedent. One of the most common forms of anaphoric dependency is the type of coreference where the antecedent is a simple noun or noun phrase and the anaphoric element is a pronoun, e.g. *Mary talked to PETER* [*antecedent*] *on the phone, while HE* [*anaphor*] *munched some M&Ms*.

In the context of the resolution of coreferential dependencies, the term *accessibility* of an antecedent is taken to refer to its relative activation in working memory during sentence or discourse processing. Thus, accessibility is a determinant in the process of resolving the relation between anaphoric devices and their antecedents. Linguists, focusing on functional aspects of language and language processing [1], have long pointed out that the *accessibility* of an antecedent is a central aspect that crucially influences the ease with which coreferential relations within and across sentences can be resolved. The acceptability of pronominal reference depends on the relative degree of accessibility of an antecedent noun, e.g. the longer the distance between antecedent and anaphor, the less accessible is the antecedent at the point where the pronoun occurs, and the more difficult it is to work out the coreferential dependency.

One of the factors which affects the accessibility of an antecedent is its *salience* in a given linguistic environment. Saliency-related determinants range from morphological, syn-

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tactic and semantic characteristics to surface features of words, such as the lexical frequency of a word in a language. Low frequency words, such as '*treacle*', attract attention, i.e. they are typically highly salient.

Psycholinguistic research has shown that the processing of low frequency compared to high frequency words involves higher processing costs, as revealed by longer reaction times and higher error rates in a variety of language-related tasks [12]. Another well-known effect of word frequency is the modulation of neurophysiological parameters. The time course and morphology of certain well-established event-related potentials (ERPs) like the N400 [20,29], or the P300 [18,20] are characterized by more negative-going amplitudes and/or longer peak latencies when subjects deal with low frequency words as compared to words which occur more often in everyday language.

In contrast to the homogeneity of results concerning these classical effects of word frequency, it is much more controversial, whether and how the relative frequency of an antecedent noun affects the processing of coreferential pronouns. In a recent eye-tracking study, van Gompel and Majid [28] described a *reverse* word frequency effect which they observed in the context of pronominal coreference resolution. The authors report shorter first-fixation, first-pass and total reading times for post-anaphoric regions in a sentence reading task. They explained these findings in recourse to Pynte and Colonna's *saliency account* [19] which suggests that general processing factors such as attention allocation and efficiency of encoding into short term memory (STM) mediate pronominal processing. Low frequency words are highly salient entities, which makes them more accessible and easier to re-access from STM at the point where a coreferential pronoun occurs in discourse. Van Gompel and Majid's results contradict the findings of Simner and Smyth [23], who predicted that no effects of the antecedent's relative frequency should be found during pronominal processing. According to Simner and Smyth's Anaphoric Lexical Access hypothesis (ALA), the word frequency of an antecedent cannot influence pronominal resolution, because anaphors target only the lemma information of their antecedents. However, since frequency information resides at the lexeme level of the mental lexicon, no frequency effect triggered by the antecedent can occur when the anaphor is resolved.

The present study used ERP measures for the online investigation of the word frequency effect in coreference resolution. Electrophysiological methods have provided reliable insights into the way word frequency influences language processing and can be expected to resolve these conflicting experimental results.

Previous ERP studies on anaphoric processing have typically focused on syntactic or semantic integration processes at the point were an anaphor occurs in a sentence. One of the most extensively investigated topics is the influence of morphological information on pronominal resolution. Violations of syntactic gender and/or number agreement between antecedent and pronoun or violations of gender stereotypes typically evoke higher amplitudes of the P600/SPS (syntactic positive shift) which is thought to be indicative of syntactic processing mechanisms [11,14,15,21].

Studies of pronominal processing which investigated the influence of discourse related factors such as parallelism of sentence structures [26] or semantic distance between antecedents and pronouns [25] report differential N400 effects, which are interpreted as reflecting difficulties with the semantic integration of pronouns into the sentence context.

Finally, differences in the load on working memory in the course of coreference resolution are typically reflected in more negative-going deflections at (left) anterior electrode sites [25]. For example, when more than one potential antecedent has to be kept active in working memory during sentence processing, i.e. when pronouns are referentially ambiguous, a sustained anterior negative shift in the ERP waveforms can be observed [27].

Twenty-seven healthy, right-handed students (20 females, 7 males, mean age 22.8, S.D. = 4.65) participated in this experiment in return for either course credit or payment. All participants were German native speakers and had normal or corrected-to-normal sight.

Experimental stimuli consisted of 150 sentence pairs. For each of these, the first sentence contained a full noun phrase and the second sentence a pronoun which referred back to it. The head nouns of the noun phrases each belonged to one of three different word frequency classes (high, middle, low) which were taken from the CELEX German database [2]. The mean log frequencies of occurrence per million words were 2.68 (S.D. = 0.26) for high frequency words, 1.79 (S.D. = 0.32) for the middle frequency class, and 0.48 (S.D. = 0.36) for low frequency words. The three classes did not differ significantly with respect to word length ($M = 5.72$, S.D. = 1.2 versus $M = 6.44$, S.D. = 2.01 versus $M = 6.52$, S.D. = 1.93, $F(2) = 2.535$, $p = .083$). Relevant semantic variables such as concreteness, animacy, and emotional valence were matched across frequency classes by constructing word triplets with very similar meanings, such as the German nouns GENOSSE (high), KAMERAD (middle) and GEFÄHRTE (low), which all translate to the English word 'comrade'.

On the basis of these matched nouns, triplets of regular paired sentences were constructed which were identical with respect to their syntactic structure, syntactic and semantic complexity, and the relative positions of nouns in the first sentences and pronouns in the second sentences, e.g. *Die große Familie mietet ein Haus* [*obj.*, *neutr.* – *high frequency*]. *Sie berät*, *wie man es* [*obj.*, *neutr.*] *vernünftig aufteilen könnte*. – *Der alte Herr bewohnt eine Wohnung* [*obj.*, *fem.* – *middle frequency*]. *Er überlegt*, *wie man sie* [*obj.*, *fem.*] *hübsch möblieren könnte*. – *Der rüstige Rentner kauft eine Laube* [*obj.*, *fem.* – *low frequency*]. *Er grübelt*, *wie man sie* [*obj.*, *fem.*] *praktisch einrichten könnte*.

Ambiguity in pronoun reference was avoided using syntactic gender and number agreement, i.e. for each pronoun there was only one preceding noun phrase which it could possibly refer to. In order to ensure that the pronouns' own relative word frequencies did not influence their processing, the numbers of the occurrences of different pronouns and pronoun forms were matched for all three conditions. The words preceding the critical pronouns where always the same for each sentence of a triplet. Furthermore, since salience of words in a given linguistic context is a relevant theoretical concept in our study, and since

sentence subjects are salient entities by definition, stimuli were constructed so that the antecedent noun phrases were always in object position. For each sentence pair, a verification question was provided (yes/no). Answering these questions required the participants to process the sentences semantically and to establish the correct coreferential relations.

Participants were seated in front of a computer display. After a short training period, the 150 sentence pairs were presented visually in randomized order in a word-by-word format. A fixation marker appeared in the middle of the screen for 300 ms prior to sentence presentation. Each word of the paired sentences was presented in the middle of the screen for 400 ms (ISI: 300 ms). Participants were asked not to move and to avoid eye blinks during sentence presentation. Between individual trials, a blank screen appeared for 2000 ms. No filler items were included.

Verification questions appeared immediately after sentence presentation. Subjects were instructed to silently read the stimuli and to respond to the questions by button press. Response accuracy was recorded.

Continuous EEG was recorded from 27 Ag/AgCl electrodes placed according to the international 10–20 system. Horizontal and vertical eye movements were recorded bipolarly (sub- and supra-orbital, right and left outer cantheal sites). All electrodes were online referenced to linked mastoids and offline re-referenced to an average over all electrodes, excluding the EOG-channels [16]. Electrode impedances were kept below 5 kΩ for the EEG recordings and below 10 kΩ for the EOG. The recordings were amplified using a BrainAmp system (BrainProducts). Sampling rate was 250 Hz.

EEG waveforms were filtered (bandwidth: 0.1–30 Hz, 24dB/oct) and controlled for artifacts (i.e. ocular artifacts, drifts and amplifier saturation) using an automatic rejection procedure (cutoff: ±40 μV). Trials containing artifacts were excluded from further analysis. The remaining trials (67%) were evenly distributed across all conditions. The continuous EEG data were segmented into single trials (interval: −100 – 700 ms), time locked to the presentation onset of antecedent nouns and coreferential pronouns in the paired sentences. After baseline correction (baseline: −100 – 0 ms before onset of the critical words), average ERPs were determined across all remaining trials for each participant by condition and recording site. Global activation was calculated on averaged data from all electrodes (root mean square or RMS values, i.e. calculation of the square root of the mean of the squared potentials over all electrodes), and grand-average ERPs over all subjects were computed. ERPs were low-pass filtered offline with 10 Hz filter for presentation purposes. All statistical analyses were performed on the unfiltered data.

Statistical analyses consisted of repeated-measures analyses of variance for mean amplitudes over time-windows, which were determined by visual inspection of the grand average waveforms. In a first step, amplitude differences across different conditions were computed for the RMS values using single-factor ANOVAs with FREQUENCY (high/middle/low) as within-subject factor. In a second step, three clusters of electrodes were selected, consisting of seven electrodes each (anterior: F7/F3/Fz/F4/F8/FP1/FP2; central: FC1/FC2/C3/Cz/C4/CP1/CP2; posterior: P7/P3/Pz/P4/P8/O1/O2). Two-factor ANOVAs, using the within-subject factors REGION (anterior/central/posterior) and FREQUENCY (high/middle/low), were calculated on mean amplitudes for each time-window. Greenhouse-Geisser corrections were applied to the degrees of freedom where necessary. Significant interactions were evaluated by post-hoc tests. Only significant amplitude differences are reported in the following section.

The mean proportion of errors did not differ significantly between conditions, $F(2,52) = 0.23$, $p = .791$ (high: $M = 0.05$, S.D. = 0.06; middle: $M = 0.04$, S.D. = 0.07; low: $M = 0.06$, S.D. = 0.06).

Upon first inspection of the ERP plots, a sustained negative component at central electrodes between 300 and 500 ms after stimulus onset is discernible, with a more negative deflection for middle frequency nouns compared to high frequency nouns, and with low frequency nouns showing the largest amplitudes (Fig. 1). Root mean square values (RMS) in this time window (300–500 ms) did not differ between the three conditions, i.e. a repeated-measures ANOVA did not reach significance for overall amplitude differences between the three conditions across all electrodes, $F(2,52) = 2.50$, $p = .091$.

A two-factor ANOVA with word FREQUENCY and REGION as within-subject factors revealed a significant main effect of REGION, $F(2,52) = 28.11$, $p < .001$, and a significant interaction FREQUENCY × REGION, $F(4,104) = 3.83$, $p = .015$. Post-hoc tests showed a significant effect of FREQUENCY at central electrodes, $F(2,52) = 4.40$, $p = .017$.

Given its latency and distribution over the scalp, this negativity can be interpreted as an instance of the N400. These findings are fully compatible with other ERP studies of word frequency effects [20,29].

Fig. 2 displays grand average ERPs elicited by the coreferential pronouns for nine electrodes. The plots reveal a strong positive-going ERP component at posterior electrodes with an onset around 250 ms and a concomitant negative deflection at (left) anterior recording sites. RMS analysis (time window: 250–450 ms) revealed a significant effect of the antecedent noun's frequency class during pronoun processing, $F(2,52) = 3.88$, $p = .027$. The amplitudes of the average waveforms were largest for the low frequency condition, and smallest for pronouns referring to high frequency nouns, with the middle category showing an intermediate deflection.

Repeated measures ANOVAs (time window: 250–450 ms) yielded a significant interaction FREQUENCY × REGION, $F(4,104) = 2.88$, $p = .046$, and a main effect of REGION, $F(2,52) = 56.43$, $p < .001$. The main effect of FREQUENCY was of marginal significance, $F(2,52) = 2.60$, $p = .084$.

Separate post-hoc tests found an effect of FREQUENCY for the posterior electrode cluster, $F(2,52) = 4.330$, $p = .018$. Separate analyses of the left-anterior deflection of the ERP waves yielded no significant effects of FREQUENCY for a cluster of three left-anterior electrodes (F3, F7, FC5), $F(2,52) = 1.56$, $p = .222$.

The scalp distribution of the evoked potential with its positive deflection at posterior electrodes, and the time-window of its occurrence (peak detection procedures yield a peak latency

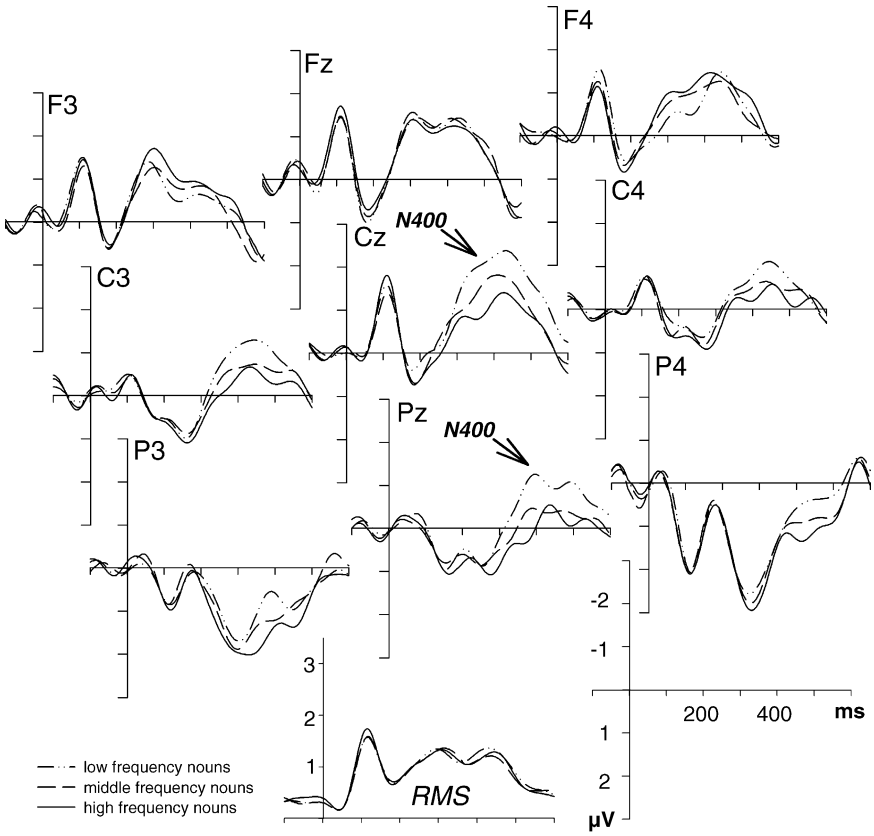

Fig. 1. Grand average ERP and RMS waveforms (average-referenced) elicited by antecedent nouns of low, middle, and high frequency; recorded at nine prominent electrode sites.

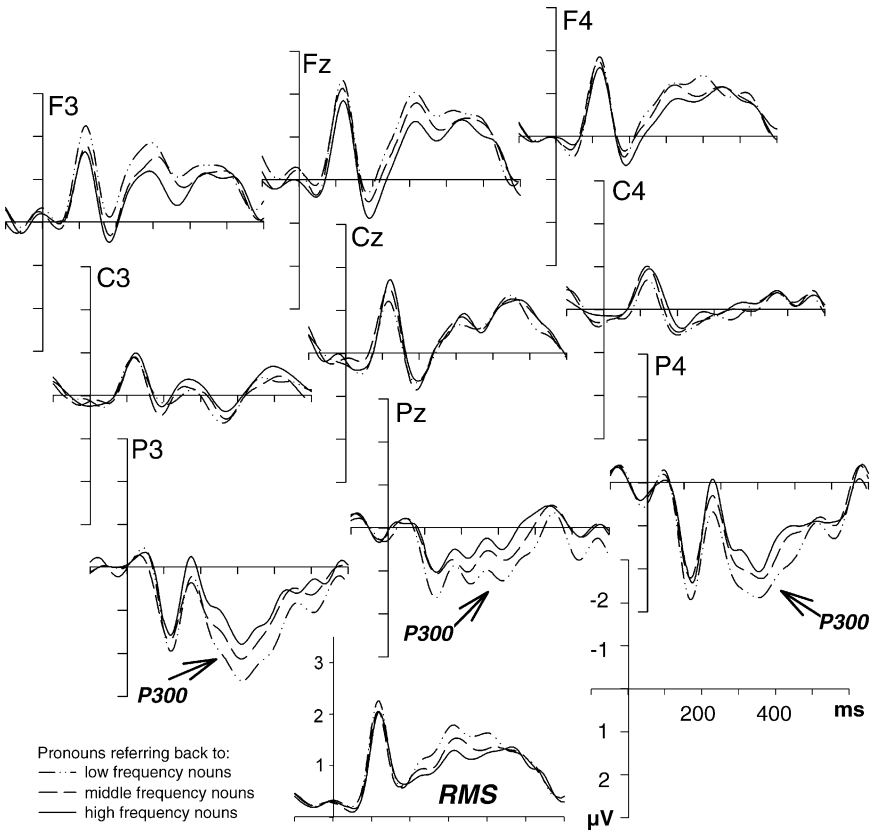

Fig. 2. Grand average ERPs (average-referenced) from nine recording sites and RMS waveform, time-locked to the presentation of pronouns referring back to low, middle, and high frequency antecedents.

of around 300 ms at parieto-occipital electrode sites, e.g. P3: $M = 302.76$ ms, S.D. = 52.06; P4: $M = 286.12$ ms, S.D. = 48.23) leads to identification of this component as a member of the P300 complex, or, more precisely, as a P3b [16].

The aim of the present study was to shed light on the controversial issue of whether the relative lexical frequency of antecedent nouns affects the resolution of pronominal anaphors. While some behavioral studies found no such frequency effects [23], data from a recent eye-tracking experiment suggest that coreferential pronouns are processed faster if the antecedent is a word with low frequency compared to more frequent nouns [28]. This *reverse frequency effect* was explained in terms of the relative salience of a low frequency word in its sentential context. For the present investigations into these contradictory result of other studies we used event-related potentials, which have been shown to be a sensitive measure of the effects of the relative frequency of words on language processing.

The graded negative-going deflection around 400 ms evoked by antecedent nouns can be interpreted as an N400 component, which is known to reflect the semantic processing of linguistic stimuli. The amplitude of the N400 was previously shown to covary in a systematic way with the relative difficulty of integrating a word into the ongoing sentence or discourse context [13]. Apart from its sensitivity to a word's lexical integration into message-level representations held in working memory [4], the N400 is also implicated in processes of accessing information from long-term memory and in the organization of information in semantic memory itself [7]. In the context of the present study, the finding of an N400 effect for antecedent nouns amounts to a reliable way of validating our three word frequency classes empirically. The meanings of high-frequency words are easier to be accessed and/or easier to be integrated into the ongoing sentence context.

The ERP component elicited by the coreferential pronouns is qualitatively different from the effects at the nouns. The large positivity at posterior electrodes which peaks around 300 ms after onset of the pronouns strongly suggests a P3b [16].

The interpretation of this ERP effect, i.e. largest P300 amplitudes for pronouns referring to low frequency nouns and smallest amplitudes for the high frequency condition, is not as straightforward as it is for the frequency effect at the noun – especially since classical ERP studies on anaphoric processing, which focus mainly on semantic or syntactic processes in the context anaphoric resolution, report qualitatively different ERP components [11,14,15,21,25,26].

However, it is indisputable that the relative frequency of the nouns *does* affect the process of pronoun resolution. This finding is thus not compatible with theories assuming no such influence of the antecedent frequency [23]. Secondly, the ERP effect for the pronouns differs fundamentally from the classic frequency effect at the nouns. It seems reasonable to assume that these differences reflect distinguishable underlying processes, thus challenging theories assuming similar lexical access for antecedent nouns and their coreferential pronouns [22]. Furthermore, an ERP effect related to the antecedents' relative word frequency which is observable within 200–400 ms after onset of a coreferential pronoun corroborates theories that assume immediate referential access in sentence processing [27].

As to the question of what the cognitive processes are that the amplitude differences of the parietal positivity are indicative of, a conclusion is difficult to reach. Although the P3b is one of the most extensively investigated ERP waves, there are currently two mutually exclusive approaches, which both aim at explaining the functional significance of this component. The first describes the P3b as reflecting processes of memory-updating in response to rare target events. According to the Context-Updating Theory [6], the amplitude of P3b is an indicator of the adaptation of working memory traces when new or *unexpected* information has to be integrated into an individual's model of the environment. Alternatively, the Context-Closure Theory [30] proposes that the P3b is evoked by *expected* stimuli. This second approach assumes that this ERP component is an index of the closure of a perceptual epoch or internal template when expectations regarding target stimuli are met.

What the current theoretical approaches to the functional significance of the P300 component have in common, is the fact that the allocation of attentional resources lies at the core of all of them [17]. The amplitude of the P3b varies proportionally with the amount of attentional resources invested in the processing of relevant stimuli [24].

Focusing on attention-related aspects of cognitive processing mechanisms in the context of coreference resolution is consistent with the *saliency account* [19] as well as with other psycholinguistic models of pronoun resolution [8]. Furthermore, the so-called Identity Thesis put forward by Coulson et al. [5] also emphasizes the relevance of attentional salience of stimuli. Coulson et al. argued that the P600, a late positive ERP component typically evoked by grammatically irregular or untypical sentence constructions and thought to reflect syntactic binding or *unification* operations, is actually a member of the P300-family [9,10]. The authors showed that increasing the relative saliency of grammatical violations increases the amplitude of the late parietal positivity, just as the salience of the noun modulates the P300 amplitude for pronouns referring back to them in the case of our study. The amplitudes of P300 components vary systematically with the relative ease of recognition of relevant stimuli.

This interpretation may also help to shed light on the question of why the present study found higher P300 amplitudes for pronouns referring back to *low-frequency* nouns, while Polich and Donchin [18] reported larger positive deflections for *high-frequency* words. In the Polich and Donchin study, the P300 amplitude correlated positively with subjects' reaction times in the lexical decision task. The same pattern applies to the data on pronoun resolution. Van Gompel and Majid [28] showed that reading times are faster for pronouns following low-frequency antecedents, for which the present ERP study finds the highest P300 amplitudes. These findings thus indicate that the more pronounced the late parietal positivity is, the faster the stimuli seem to be processed.

In summary, the ease of processing coreferential dependencies is affected not only by syntactic or semantic variables, it also depends on surface characteristics of words such as relative word frequency. Our ERP study revealed an effect of the antecedents' lexical frequency at the point where an anaphor

occurs in a sentence. This effect was interpreted in domain-general terms of the allocation of attentional resources. In order to identify the exact cognitive processes which form the basis of these effects in more detail, more sensitive EEG measures such as time–frequency analysis [3] should be employed in future studies.

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