Word class and word frequency in the MMN looking glass

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Abstract

The effects of lexical meaning and lexical familiarity on auditory deviance detection were investigated by presenting oddball sequences of words, while participants ignored the stimuli. Stimulus sequences were composed of words that were varied in word class (nouns vs. functions words) and frequency of language use (high vs. low frequency) in a factorial design with the roles of frequently presented stimuli (Standards) and infrequently presented ones (Deviants) were fully crossed. Deviants elicited the Mismatch Negativity component of the event-related brain potential. Modulating effects of lexical meaning were obtained, revealing processing advantages for denotationally meaningful items. However, no effect of word frequency was observed. These results demonstrate that an apparently low-level function, such as auditory deviance detection utilizes information from the mental lexicon even for task-irrelevant stimuli.

Introduction

Auditory deviance detection involves both sensory and categorical sound representations (Dehaene-Lambertz, 1997; Phillips et al., 2000; Winkler et al., 1999b; for a review, see Näätänen et al., 2001). Previous research demonstrated that the deviance detection process is modulated by the lexical status of spoken words (Jacobsen et al., 2004; Pulvermüller et al., 2001; Shtyrov & Pulvermüller, 2002a and b; for reviews, see Pulvermüller & Shtyrov, 2006; Shtyrov & Pulvermüller, 2007). In a series of studies, Pulvermüller and his colleagues (2001; Pulvermüller & Shtyrov, 2006) found stronger deviance detection for meaningful than for meaningless deviant speech stimuli. Lexical category was also shown to affect the detection of deviants within sequences of task-irrelevant speech stimuli (e.g., Hasting et al., 2008). Furthermore, Jacobsen and his colleagues (2004) showed that deviance detection is enhanced within the context of meaningful words, as compared to the context of pseudowords, phonologically legal non-words of a given language. However, in a follow-up study employing non-speech stimulus material, they found that the differences observed between words and pseudowords in deviance detection may not depend on meaningfulness; rather, these effects may be explained by "familiarity", with the existence of a long-term memory trace for the stimuli (Jacobsen et al., 2005). The present study was designed to disentangle the effects of meaningfulness from familiarity on auditory deviance detection. To this end, two word classes with different qualities of meaningfulness and high vs. low word frequency (operationalizing familiarity) were contrasted in an auditory oddball design. Because these two variables play an important role in language processing, results were expected to shed light on the role of lexical and general memory processes in auditory deviance detection, the timeframe of lexical access and the interpretation of auditory deviance detection within the context of speech perception.

The outcome of auditory deviance detection is reflected by the mismatch negativity (MMN) event-related brain potential (ERP) component and its magnetic counterpart, the MMNm (for reviews, see Kujala et al., 2007; Näätänen et al., 2007). MMN is elicited, when an auditory event (termed "deviant") differs from that extrapolated from the regularities detected (termed the "standard") within the preceding auditory stimulation (Näätänen & Winkler, 1999; Winkler, 2007). The MMN-generating process is neither volitional, nor does it require attentive selection of the sounds. In other words, MMN is elicited whether or not the sounds are relevant for the participant's task (see Näätänen, 1992; Sussman, 2007; Sussman et al., 2003b). Deviation from various simple, complex, and even abstract auditory regularities has been shown to elicit MMN. Thus, the MMN can be used to study what kinds of analyses have been performed on task-irrelevant sounds, along with its mental chronometry.

The electrically recordable MMN component appears as a negative deflection in the ERP, reaching its peak between 100 and 250ms from the onset of the deviation. It shows a maximal (negative) amplitude over fronto-central scalp areas often appearing with reversed polarity at electrodes positioned over the opposite side of the Sylvian fissure, such as the mastoid leads (e.g., Schröger, 1998). These features of the MMN component stem from its predominantly auditory cortical origin, although the electrically recorded MMN wave also receives contribution from frontal generators (e.g., Alho, 1995; Deouell, 2007).

Auditory memory-based deviance detection is affected by information stored in long-term memory. It has been shown that training has long-term effects on what regularities are detected for task-irrelevant sounds as well as on the precision of the regularity representations. For example, professional musicians detect, attentively as well as in passive situations (as measured with the MMN) more complex regularities and smaller acoustical changes, but only for familiar sounds and/or within familiar contexts (e.g. Brattico, Näätänen & Tervaniemi, 2002; van Zuijen et al., 2004; for a review, see Schröger, Tervaniemi & Huotilainen, 2004). Training with unfamiliar sounds was shown to result not only in improved active discrimination, but also in detecting changes in passive situations hours, days (e.g. Atienza & Cantero, 2001; Huotilainen et al., 2001; Näätänen et al., 1993), or even months (Kraus et al., 1995) after the original training session.

Language-specific effects on auditory deviance detection

Language-specific memory representations can also influence the detection of auditory deviance for task-irrelevant speech stimuli (for a review, see Näätänen, 2001). For example, in a cross-linguistic study with Hungarian and Finnish participants, Winkler and his colleagues (Winkler et al., 1999b) used within- and across-category phoneme contrasts that were reversed for the two languages. By means of this crossed design, they demonstrated that the MMN-generating process simultaneously operates both on the basis of auditory sensory memory and categorical phonetic stimulus representations (for similar conclusions, see Dehaene-Lambertz, 1997; Näätänen et al., 1997; Phillips et al., 2000; Sharma & Dorman, 2000). These results suggest that linguistic information trigger processes, which prepare the auditory system for detecting language-specific auditory deviations. In other linguistic studies of MMN, parallel perceptual and MMN measures have been obtained for phoneme prototypes (the ”perceptual magnet effect”; Kuhl, 1991; Aaltonen et al., 1997), phonotactics (e.g., Steinberg et al., 2010), or language training (Kraus et al., 1995; Winkler et al., 1999a). Further, MMR (“mismatch response”, the response to auditory deviance in infants) has been useful in the study of language development (e.g., Cheour et al., 1998; Háden et al., 2020; Ylinen et al., 2017). These results suggest language-specific processing of task-irrelevant speech sounds.

This conclusion brought up the possibility of lexical, syntactic, and semantic analysis of task-irrelevant speech sounds. Basing on EEG and MEG results, Pulvermüller and his colleagues (Pulvermüller et al., 2001; Shtyrov & Pulvermüller, 2002a and b; for a review, see Shtyrov & Pulvermüller, 2007) suggested that task-irrelevant words undergo lexical analysis.

In a typical study of the series of experiments, (Pulvermüller et al., 2001), isolated syllables were presented in random succession at a 450 ms stimulus onset asynchrony (SOA). On 16% of the trials, a succession of two of these syllables resulted either in a word or a pseudoword deviant. Higher-amplitude MMNms were elicited by word deviants than by pseudoword deviants. The authors interpreted these and other similar results (although see Diesch et al., 1998) as reflecting the ”presence of memory traces for individual spoken words in the human brain” (p. 607, Abstract). However, Winkler et al. (2003a) found no difference between MMNs elicited by the same word contrast when the two words had the same or two different meanings (allophonic variants of the same word in Hungarian, while two different words in Finnish, presented to bilinguals in the two different language contexts). This result is at odds with the hypothesis that the specific meaning of the standard and deviant speech sounds affected the deviance detection process reflected by MMN. On the other hand it does not contradict the hypothesis that lexical analysis per se would affect MMN (see also Muller-Gass et al., 2007, for a finding of automatic processing of lexical changes for task-irrelevant speech stimuli). Word frequency has been demonstrated to modulate the MMN amplitude (Alexandrov et al., 2011; Shtyrov, 2011). Unfamiliar, phonologically legal phoneme sequences, i.e. pseudo-words, elicit altered, larger MMN amplitudes after lexical training (Shtyrov et al., 2010 ; Partanen et al., 2017).

In a previous study (Jacobsen et al., 2004), we tested the effects of lexical status of both the frequent (standard) and the infrequent (deviant) stimulus on the MMN response. Stimulus sequences were composed of words that were lexical and meaningful in Hungarian, but non-lexical, and meaningless, while phonologically and phonotactically legal in German, and words with the opposite characteristics regarding the two languages. The roles of the frequently presented stimuli (standards) and infrequently presented ones (deviants) were fully crossed: Word standard with word deviant, word standard with pseudoword deviant, pseudoword standard with word deviant, and pseudoword standard with pseudoword deviant;

note that what was a ”word” in one language was a ”pseudoword” in the other language and vice versa. Both, word and pseudoword deviants elicited the MMN component in both Hungarian and German listeners. We observed higher MMN amplitudes when the standard was a word in the listener’s native language versus when it was not. For deviants, the similar tendency did not reach statistical significance.

On the basis of these results, we suggested that either the lexical status (including the potential for extracting meaning) of, or the participant’s familiarity with, the standard words affected the context within which deviants were evaluated, and thus altered the deviance detection process, as was reflected in the observed MMN amplitude differences. Our notion of familiarity includes the existence of long-term memory representations for the given stimuli. Previously unfamiliar stimuli repeatedly presented in a given situation do not immediately lead to changes in long-term memory representations and, therefore, we do not consider such stimuli as familiar items. For acoustic material, this distinction is supported, amongst others, by results showing changes in the MMN responses measured immediately after learning a difficult auditory discrimination and following periods of sleep (e.g, Atienza & Cantero, 2001; Atienza et al., 2004). The above described cross-language study could not distinguish between these two possibilities, because lexical status and familiarity were linked in this study. The question is, however, an important one. If the MMN effects found in our previous study (and, perhaps also those of Pulvermüller and his colleagues) were caused by the lexical status of the speech stimuli, then these results demonstrate the operation of lexical analysis on task-irrelevant (perhaps even unattended) speech sounds. In contrast, if these effects were caused by the participants’ differential familiarity with words of their language as opposed to pseudowords, then these findings reflect a more general effect of long-term memory representations on detecting auditory deviance in sequences of task-irrelevant stimuli. In the latter case, similar effects should be obtained for non-speech stimuli. This was tested in a follow-up study presenting non-linguistic stimuli (Jacobsen et al., 2005). The results showed that both familiar deviants and familiar context (standards) enhanced the MMN amplitude, allowing for a confound between familiarity and meaning.

Thus familiarity (the existence of a long-term memory trace) for standard and/or deviant sounds affects the deviance detection process reflected by MMN. These results are compatible with the notion of long-term memory traces being activated even without focused attention (e.g., Bower & Hilgard, 1981). However, the above results do not rule out the possibility of the lexical, and linked with it, even semantic analysis of task-irrelevant speech sounds. In fact, results showing lexical category (Hasting et al., 2008) and syntactic effects on auditory deviance detection (Hasting et al., 2007) imply that lexical analysis should also affect this process. The current study was designed to separate lexical category/meaningfulness from familiarity and test these effects separately for deviant and standard stimuli on auditory deviance detection.

Experimental design

Lexical category/meaningfulness was manipulated by employing two word classes. The concrete nouns, chosen for the present study have denotational meanings that are imaginable. They may be considered to belong to the open class of words in the lexicon (for theories of the mental lexicon see e.g., Scarborough, Cortese, & Scarborough, 1977; Levelt, Roelofs, & Meyer, 1999; Bybee, 2006). In contrast, the functions words are more abstract and general, having meaning for phrase or sentence level processing. They are members of the closed class . Lexical familiarity was varied by using words of high or low word frequency in German. Variation in word frequency was equally applied to both word classes resulting in a fully crossed design with respect to the two experimental variables. In the experiment, spoken words were presented in oddball blocks to participants who ignored the acoustic stimulation while watching a silent subtitled movie. The design allowed comparing MMN modulation effects between noun and function word deviants as well as between highly frequent (familiar) versus less frequent (less familiar) words. Furthermore, the design also allowed comparisons between responses elicited by the same deviants when they appeared in the context of nouns vs. function words as well as that between the contexts of highly frequent versus less frequent words.

The following hypotheses were tested. If MMN is only modulated by the presence vs. absence of a lexical trace (Hypothesis I), no modulating effects of word class should be found on the MMN in the current study, because all items have representations in the mental lexicon. If, however, differential lexical meaning is important for long-term effects on auditory deviance detection, an effect of word class should be observed in the present study, because nouns differ in lexical meaning from functions words. There are two possible ways in which lexical meaning (word class) could enhance auditory deviance detection: through the meaningfulness of the deviant (as was originally suggested by Pulvermüller et al., 2001; Hypothesis II) and of the context (standards; as was originally suggested by Jacobsen et al., 2004; Hypothesis III). It is also possible that highly frequent, i.e., more familiar word deviants elicit an MMN of higher amplitude than less familiar ones (Hypothesis IV). This latter hypothesis is a specific application of the familiarity account put forward by Jacobsen et al. (2005). As word frequency was not controlled as a factor in a number of studies on pre-attentive lexical processing (e.g., Jacobsen et al., 2004), it is a good candidate variable accounting for discrepancies between earlier studies. Effects of word frequency (Alexandrov et al., 2011; Shtyrov et al., 2011) could help to illuminate the partly incongruous pattern of MMN results of experiments using lexical items (e.g., Pulvermüller et al. 2001; Diesch et al., 1998; Jacobsen et al., 2004). Finally, familiarity of the context (standards) may also increase the MMN amplitude, as was suggested by Jacobsen and colleagues (2004 and 2005). The familiar context hypothesis suggests (Hypothesis V) MMNs of higher amplitude to be elicited by deviants appearing in the high frequency as compared to the lower frequency context, irrespective of the level of familiarity of the deviant item.

Method

Participants

Twenty-four volunteers participated in the study (12 men). They were native speakers of German, and their median age was 24 years (range 19–35). All participants were right-handed, reported normal auditory and normal or corrected-to-normal visual acuity, and no neurological, psychiatric, or other medical problems. Participants gave informed consent, and received course credit or monetary compensation. The experimental protocol conformed to the Declaration of Helsinki and the ethics guidelines of the German Association of Psychology (ethics board of the Deutsche Gesellschaft für Psychologie, DGPs: http://www.dgps.de/dgps/aufgaben/ethikrl2004.pdf).

https://web.archive.org/web/20091122155535/http://www.dgps.de/dgps/aufgaben/ethikrl2004.pdf

Stimuli

The stimuli were eight nouns (open-class words) and eight function words (closed-class words). The sixteen items (Table 1) were chosen from a database of the Institut für Deutsche Sprache (IDS, Mannheim, Germany) with the premise that half of the nouns as well as half of the function words had a high, the remaining halves a low frequency of occurrence in written German (taken here as reflecting language usage). Across the four categories, word length and onsets were matched as well as possible while satisfying the other constraints for item selection. The resulting stimulus set comprised one di- and three monosyllabic words per word class and category of frequency of usage.

For each of the 16 items, five exemplars uttered by different female native speakers of German were used. Prior to the experiment, several exemplars of the words were recorded from the five speakers in a sound-proof room. For each speaker, a complete set of all 16 words was selected that were spoken clearly and with neutral expression. Measurements of the fundamental frequencies (median F0) of the stimuli using Praat (Boersma & Weenink, 2020) are given in the supplementary material. Stimulus variation, 20 physically different stimuli for each cell of our 2 x 2 experimental design, was introduced in order to induce abstraction processes of the auditory system and, thus, render our results less likely to hinge on stimulus specificities. Intensities were normalized, and stimuli were presented at approximately 65dB SPL.

---------------- Table 1 ----------------

In the main experiment, each participant encountered only two of the four items (see Table 1) from each of the four word categories (2 word classes × 2 frequencies of usage). Subsets were counterbalanced across participants such that each word item contributed equally to the experiment as a whole. All five speakers' exemplars of the selected items were presented to the participant with equal probabilities.

Experimental design and procedure

Word class (nouns vs. function words), frequency of usage (high vs. low) and stimulus role (standard vs. deviant assignment in the oddball protocol) were varied as independent factors in the experimental design (Table 2). Experimental conditions in which the standard and the deviant simultaneously differed in both factors (word class and frequency of usage; e.g., low-frequency noun for standard combined with high-frequency function word as deviant) were omitted from the experimental design (the diagonal from lower left to upper right in Table 2). This resulted in an incompletely crossed 2x2x2 experimental design (2 word classes × 2 frequencies of usage × 2 stimulus roles) with 12 different experimental conditions. The experimental conditions were presented in separate stimulus blocks, one block per condition. In each stimulus block, one word served as the frequently presented stimulus (the standard) with a within-sequence probability of 87 % and a different word served as the infrequently presented stimulus (the deviant) with a within-sequence probability of 13 %. In the experimental design, four-four conditions are mirror images of each other (the upper right and the lower left triangles in Table 2): e.g., the condition with a high-frequency noun standard and high-frequency function-word deviant is the mirror image of the condition with high-frequency function-word standard and high-frequency noun deviant. Using the same words in the mirror image conditions with opposite within-sequence probabilities allowed us to delineate the MMN response by subtracting responses elicited by identical stimuli, which differed only in their role within the stimulus sequences. There were, however four conditions, which contrasted words with identical levels in both factors (e.g., high-frequency noun as both standard and deviant; the diagonal from upper left to lower right in Table 2). In order to calculate MMN similarly for these conditions, we added four additional conditions (stimulus blocks), in which the role (within-sequence probability) of the two words was reversed, making up altogether 16 stimulus blocks. As a result, an equal number of each of the selected word exemplars was presented to the participant during the experimental session. That is, across the 384 blocks of the whole 24-participant experiment, each word was presented as a deviant in 24 blocks: the given word was paired 4-4-4 times with the other three words in the same word class - frequency combination listed in Table 1; it was paired six times with a word that differed only in its frequency; and it was paired another six times with a word that differed only in its word class. In another 24 blocks (across the whole 24-participant experiment) the same word was presented as a standard with the same pairs as deviants, to the same participants. For example, in a deviant role "Nerz" (a low-frequency noun) was paired 4 times with "Alm", 4 times with "Boje", 4 times with "Damm" (which are all low-frequency nouns), 6 times with "Bett" (a high-frequency noun) and 6 times with "desto" (a low-frequency function word). In another 24 blocks the same word-pairs with reversed roles (i.e. "Nerz" as standard) were presented.

---------------- Table 2 ----------------

Participants were comfortably seated in an electrically shielded and sound-attenuated experimental chamber (International Acoustic Company) and were instructed to watch a self-selected, subtitled, and silenced video while ignoring the acoustic stimulation. Stimuli were presented binaurally via headphones (Sennheiser HD 25; Sennheiser electronic GmbH & Co. KG, Wedemark, Germany) with a stimulus onset-to-onset interval of 750 ms in a pseudorandomized order in which at least two standards were presented between two successive deviants.

A total of 1300 trials per experimental block was presented. The 16 experimental blocks were recorded in two sessions (8 blocks per session) with the standard/deviant stimulus assignments reversed between the two sessions. The order of the stimulus blocks was counterbalanced across participants. Experimental sessions lasted approximately 2 hours (without electrode placement and removal).

Electrophysiological recordings

The electroencephalogram (EEG; Ag/AgCl electrodes, Falk Minow Services, NeuroScan amplifier [20 participants], BrainAmp EEG amplifier [4 participants]) was recorded continuously from 11 standard scalp locations according to the extended 10-20 system (American Electroencephalographic Society, 1991; F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, LM, RM) with a sampling rate of 500 Hz. The reference electrode was placed on the tip of the nose and the ground electrode at FPz. Electroocular activity (EOG) was recorded with two bipolar electrode pairs, the vertical EOG from the right eye by one supraorbital and one infraorbital electrode, and the horizontal EOG from electrodes placed lateral to the outer canthi of the two eyes. Impedances were kept below 8 kOhm. On-line filtering was carried out using a 0.05-Hz high-pass and a 125-Hz low-pass filter.

Data Preprocessing

The EEG was bandpass filtered (1-16 Hz) off-line with Kaiser-windowed sinc finite impulse response filter (beta: 4.534; transition bandwidth: 0.5 Hz; stopband attenuation: minimum 50 dB, number of coefficients: 2929). Epochs of 600 ms including a 100 ms pre-stimulus baseline were extracted. Epochs with a signal range exceeding 75 µV on any EEG or EOG channel, as well as epochs overlapped by edge-effects caused by filtering (i.e. at the beginnings and ends of the recordings) were rejected from the analyses. For each word-speaker stimulus combination, the triggers were off-line adjusted to reflect the perceptual onset of the stimulus as signaled by the latency of the P1 response. For this adjustment, the group-average ERPs were calculated for each word (when presented as standard) and speaker combination. The P1 latency was measured at the Cz lead. The triggers for each word-speaker combination were then shifted so that the group-average P1 peaked at 80 ms from the trigger for all stimuli. The average P1-N1 latency difference was 45 ms, resulting in the N1 peak latency falling to about 125 ms. Using the latency-adjusted triggers, a new set of epochs was extracted. ERPs were computed according to the experimental factors of word class (noun vs. function word), frequency of usage (high vs. low), and stimulus role (deviants vs. standards). Comparisons of Deviant and Standard ERPs comprised physically identical stimuli. In order to take the whole MMN amplitude into account in the measurements, ERPs were re-referenced to the linked mastoids (e.g., Schröger, 1998).

Statistical analysis

Statistical calculations were performed with R (version 3.6.2, R Core Team, 2019), using the "ez" (version 4.4-0, Lawrence, 2016) and "ggplot2" (version 3.2.1, Wickham, 2016) packages. ERP effects were tested by repeated measures analyses of variance (ANOVA). For each experimental contrast, the corresponding deviant-minus-standard difference waveforms were computed. ERP peak latencies were determined by a local peak search in the group-mean difference waveforms in the 80-200 ms interval across all electrode positions. Peaks with the highest peak amplitudes were selected: The difference waveform peaks were at 146 (Fz), 120 (Fz), 134 (Cz) and 114 ms (Cz), for noun/high, noun/low, function word/high, and function word/low Word-class/Frequency-of-usage combinations, respectively. Therefore, the common, 80-ms-long window was centered at 128 ms to give substantial coverage to all the peaks (see Figure 1) For all EEG electrode positions, average voltage amplitudes were computed in identical 80ms long time windows centered on the average latency of these peaks.

An omnibus ANOVA was computed for physically identical stimulus comparisons with the factors Stimulus-Role (standard vs. deviant), Word-Class (noun vs. function word), Frequency-of-Usage (high vs. low), and two electrode position factors: Anterior–Posterior (F-, C-, vs P-lines), and Laterality (3-, z-, vs. 4-lines).

Analysis of the context effects was done for the deviant ERP responses (i.e., the effects of the features of the standard-stimulus on the ERPs elicited by the deviant stimuli). Two ANOVAs were computed. In one, Word-class of the standard stimulus and the two electrode position factors were used; in the other the Frequency-of-usage of the standard stimulus and the two electrode-position factors. Two separate 80-ms long measurement windows were established for these contrasts, based on the MMN peaks (derived from the deviant minus identical standard difference waveforms) pooled according to the levels of the contrasts: 138 ms at Fz for the noun, and at 120 ms at Cz for the function-word context; 116 ms at Cz for the high, and at 126 ms at Fz for the low frequency-of-usage context. Thus the windows were centered at 130 ms for the amplitude measurements for the Word-class context ANOVA, and at 120 ms for the Frequency-of-usage context ANOVA.

All significant effects are reported. Greenhouse-Geisser correction was applied as appropriate, and the ε correction factor is reported by the analyses. Generalized η squared effect sizes are reported (Bakeman, 2005; Olejnik & Algina, 2003).

Results

Deviant effects

Figure 1 shows the MMNs elicited in the four experimental conditions (high vs. low frequency fully crossed with nouns and function words). Deviant minus identical standard difference waveforms (re-referenced to the linked mastoids) are shown for the nine electrode locations used in the omnibus ANOVA. Figure 2 presents the measured deviant-minus-standard (MMN) amplitudes.

----------------- Figure 1 -----------------

----------------- Figure 2 -----------------

The omnibus ANOVA revealed a main effect of Stimulus-Role, as could be expected by selecting the measurement window based on the deviant-minus-standard difference peak: $F(1,23)=54.9628$, $\eta_G^2 = 0.0553$, $p < 0.001$. In the following we will focus on interactions including the Stimulus-Role factor, because only these results refer to the MMN component. The amplitudes measured for the deviant and the standard significantly interacted with the electrode's position along the Anterior-Posterior line (Stimulus-Role × Anterior–Posterior: $F(2,46)=9.844$, $\varepsilon = 0.5648$, $\eta_G^2 = 0.002$, $p = 0.0032$). Due to the presence of a three-way interaction which also included the Word-Class factor (see below), this effect is not interpreted here. There was also a significant interaction between Stimulus-Role and

Laterality ($F(2,46)=4.8535$, $\varepsilon = 0.7348$, $\eta_G^2 = 0.0002$, $p = 0.0223$) reflecting higher negative deviant-minus-standard difference amplitudes at midline than at the right side [shown by dependent Student's *t*-test between the average amplitudes: $t(23) = 4.4768$, $p = 0.0002$; *t*-tests between amplitudes at the left and right, or midline and left sites showed no significant differences: $t(23) = 0.9285$, $p = 0.3628$, and $t(23) = -1.9273$, $p = 0.0664$; respectively].

A significant three-way interaction was observed for the factors Stimulus-Role, Word-Class, and the Anterior–Posterior topographic factor: $F(2,46)=11.1931$, $\varepsilon = 0.5801$, $\eta_G^2 = 0.0008$, $p = 0.0017$. Resolving the omnibus ANOVA effect separately for the two word classes by two one-way ANOVAs on the deviant-minus-standard difference amplitudes with the Anterior–Posterior factor showed no effect for function words but a significant main effect of Anterior–Posterior ($F(2,46)=23.3047$, $\varepsilon = 0.5742$, $\eta_G^2 = 0.0749$, $p < 0.001$) for nouns (caused by decreasing difference amplitudes from the frontal towards the parietal line of electrodes: F vs C: $t(23) = -3.364$, $p<0.005$; F vs P: $t(23) = -4.933$, $p<0.0001$; C vs P: $t(23) = -5.2994$, $p<0.00005$) as is expected for the MMN component.

Finally, the significant effects not involving the Stimulus-Role factor included significant interactions between Frequency-of-Usage and Word-Class ($F(1,23)=5.4041$, $\eta_G^2 = 0.008$, $p = 0.0293$), between Word-Class and Anterior–Posterior ($F(2,46)=8.0145$, $\varepsilon = 0.6773$, $\eta_G^2 = 0.0014$, $p = 0.0043$), as well as between Frequency-of-Usage, Anterior–Posterior, and Laterality ($F(4,92)=4.2508$, $\varepsilon = 0.8378$, $\eta_G^2 = 0.0001$, $p = 0.006$) and main effects describing the EEG topography collapsed over standards and deviants (Anterior–Posterior: $F(2,46)=140.694$, $\varepsilon = 0.6616$, $\eta_G^2 = 0.2883$, $p < 0.001$; Laterality: $F(2,46)=5.5011$, $\varepsilon = 0.9027$, $\eta_G^2 = 0.0021$, $p = 0.0094$).

In summary, results obtained for the deviant and standard amplitudes suggest that MMN with typical scalp distribution has been elicited by all deviant-standard combinations (shown by the significant interactions between Stimulus-Role and the topographic factors). The frontal MMN amplitude tended to be higher for nouns than for function words ($t(23) =$

2.0253, $p = 0.0546$). MMN also differed between the two different word classes by its scalp distribution (Stimulus-Role, Word-Class, and Anterior–Posterior interaction). However, the MMN amplitude or scalp distribution did not differ for, or interact with word frequency, because Frequency-of-Usage did not significantly interact with Stimulus-Role.

Context (standard) related effects on the deviant ERP responses

Linked-mastoids re-referenced ERPs elicited by deviants in the context of the two different word classes are shown in Figure 3. Only topographical main effects were found (Anterior–Posterior: $F(2,46)=129.2478$, $\varepsilon = 0.6703$, $\eta_G^2 = 0.3108$, $p < 0.001$; Laterality: $F(2,46)=7.4231$, $\varepsilon = 0.8945$, $\eta_G^2 = 0.0037$, $p = 0.0025$).

---------------- Figure 3 ----------------

Linked mastoids re-referenced ERPs elicited by deviants in the context of high- and low-frequency words are shown in Figure 4. The ANOVA again revealed only topographical main effects (Anterior–Posterior: $F(2,46)=105.2677$, $\varepsilon = 0.6522$, $\eta_G^2 = 0.269$, $p < 0.001$; Laterality: $F(2,46)=7.2745$, $\varepsilon = 0.8809$, $\eta_G^2 = 0.0033$, $p = 0.0029$).

---------------- Figure 4 ----------------

In summary, the word class or word frequency of the context (features of the standard) did not have a significant effect on the deviant response.

Discussion

The present study tested hypotheses regarding effects of differential lexical meaning and lexical familiarity on auditory deviance detection as indexed by modulations of the MMN.

The effects of lexical meaning were tested by comparing the responses to nouns, belonging to the open class of words and having denotational meaning, with those to functions words, which belong to the closed class and have more abstract and general meaning. Lexical familiarity was varied for both levels of meaningfulness by using words with either high or low frequency of usage in German. The effects of these variables on the MMN were separately tested for the infrequent deviant stimulus and on the context provided by the frequent standard stimulus in a passive oddball paradigm using an incompletely crossed factorial design missing only those combinations of the standard and the deviant, which differed in the levels of both linguistic variables.

The direct comparison of lexical meaning and lexical familiarity revealed an effect of word class. We attribute this effect to the fact that nouns are denotationally meaningful, while function words have little or no denotational meaning of their own. In contrast, the present study found no modulating effect of the difference between highly familiar and less familiar words on the MMN.

Based on previous studies, five hypotheses had been specified and tested in the current study. The lexical trace hypothesis suggests that the availability of a lexical trace is sufficient for explaining the MMN effects found for meaningful linguistic stimuli (Hypothesis I). On this hypothesis, in the current study, no modulating effect of word class should have been found on the MMN, because all stimuli had representations in the mental lexicon. Denotational meaning, however, showed an effect on MMN scalp distribution and a tendency of an effect on the MMN amplitude. This indicates that long-term memory representations of denotational meaning affect auditory deviance detection even when the stimuli are task-irrelevant. Of the two possible ways lexical meaning could affect the auditory deviance detection processes (Hypotheses II and III) reflected by MMN, we found evidence for an effect through the meaningfulness of the deviant stimulus, while no significant effect was obtained for the context provided by the standard stimulus. This result is compatible with several previous studies (for a review, see Shtyrov & Pulvermüller, 2007), while it does not support the notion that the meaningfulness of the context affects deviance detection. Thus, whereas the existence of a lexical trace could affect the MMN component through the context (as previous studies suggesting lexical context effects contrasted lexical and non-lexical stimuli; see Jacobsen et al., 2004), the contents of the lexical representation affects MMN only through the deviant stimulus.

Familiarity with the stimuli (operationalized here as the frequency of word usage; Hypotheses IV and V) did not significantly affect the MMN. The lack of an effect of familiarity on the MMN contrasts the finding of Alexandrov and colleagues (2011). We propose two possible post-hoc explanations for this discrepancy. 1) The design of the current study eliminated the possible confounding effects of the frequency of usage of the standard word (by fully crossing standards and deviants in terms of the frequency of usage) and to some degree the acoustic/phonetic specifics of both the standard and the deviant word (by presenting 5 different exemplars of each of the 8 different high and 8 different low frequency-of-usage words). In contrast, in Alexandrov and colleagues' (2011) study, only two specific words were presented (one with high and the other with low frequency of usage) and MMN was compared between blocks within which one word was common while the other rare and vice versa. Although in Alexandrov and colleagues' (2011) study the critical comparison was between MMNs elicited by contrasting the same two words, previous studies have found asymmetry between MMNs elicited by contrasting the same two sounds with reversed roles (Nordby et al., 1994; Sabri & Campbell, 2000). Thus it is possible that in Alexandrov et al.'s study, effects related to the difference in the frequency of usage of the standard or some specific acoustic/phonetic effect of the stimuli used confounded the effect of the difference in the frequency of usage. 2) It is possible that the lack of the frequency of usage effect in the current study was because, in contrast to Alexandrov and colleagues (2011), high and low frequency of usage were not sufficiently different in the current study. Possibly even the relatively infrequently used words in our study were sufficiently familiar to native speakers, so that they fully utilized the benefits of familiarity for the deviance-detection processes reflected by MMN. Whereas previous studies reporting familiarity effects typically contrasted familiar stimuli (or ones familiarized during the experiment) with ones that participants have likely never encountered prior to the experiment (e.g., Jacobsen et al., 2005; Kraus et al., 1995; Shtyrov et al., 2010; Shtyrov, 2011; but see Alexandrov et al., 2011), the current study compared between two >0 levels of familiarity. This alternative is weakly supported by the numerically (but not significantly) higher MMN amplitudes for high- vs. low-frequency words. Future studies can test this hypothesis by comparing the MMN between stimuli with different levels of familiarization.

The current pattern of results suggests that the deviance detection process reflected by the MMN component is based not only on the statistics of the stimulus sequence within which the MMN is elicited, but also on information regarding previous encounters with the deviant stimulus. That is, long-term memory traces are activated even when the listener does not focus on the sounds and they affect the deviance detection process (see, Näätänen et al., 2001). But what is the nature of the effect of the information stored in more durable forms of memory? The “primacy bias” effect may shed some light on this question: in a series of studies, Todd and colleagues (e.g., Todd et al., 2011, 2020) demonstrated that the context within which a given stimulus is first encountered (whether it was frequent or rare as well as higher-order statistics and temporal parameters of the sequence within which it appeared), affects the MMN elicited by the stimulus in stimulus sequences encountered later. Todd and colleagues (2020) suggested that previous encounters with the given stimuli affect the estimates of the precision (e.g., Friston, 2005) or reliability (Winkler & Schröger, 2015) of internal models within a predictive scheme, which affects the strength of the response to prediction violations as indexed by the MMN (see, e.g., Winkler & Czigler, 2012). Similar first-impression bias effects have been found within various aspects of human information processing (e.g., decision making; Shteingart et al., 2013). This may be a consequence of common underlying processing principles, such as offered by the predictiong coding framework (Friston, 2005). Taking this view, various lexicality effects found for MMN (including the current one of meaningfulness) can be conceptualized in terms of modulations of the priors or precision estimates in a predictive information processing system.

This study revealed fine-grained effects. Observed modulations of the MMN were on the order of, in part, less than half a microvolt. This was the case despite the fact that the temporal jitter in the ERPs was adjusted. The latter had been introduced by our stimulus selection, that offered the auditory system stimulus variation in order to induce abstraction processes and render our results less likely to hinge on stimulus specificities. There might not have been sufficient statistical power in the present experimental setup to secure all effects, such as the context effects observed in Jacobsen and colleagues (2004; 2005) and the effect of the frequency of word usage in Alexandrov and colleagues (2011). Future studies could a) provide stronger tests of the above effects with simplified (one effect at a time) approach and b) test the notion of continuous dimensions of “meaningfulness” and how strong images are evoked by words by comparing MMN amplitudes elicited by contrasts of lower vs. higher differences in these dimensions.

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Table 1. Stimulus set and mean stimulus durations averaged across the five exemplars

	word class					
	Nouns			Function words		
frequency of occurrence	word	freq.	duration	word	freq.	duration
High	Erde (earth)	191	592 ms	aber (but)	1745	551 ms
	Kind (child)	420	593 ms	dann (then)	1800	426 ms
	Mensch (human)	1077	670 ms	doch (however)	632	457 ms
				nur (only)	2899	479 ms
	Bett (bed)	119	457 ms			
Low	Boje (buoy)	0	569 ms	desto (the [comp.])	20	650 ms
	Damm (dam)	15	369 ms			
	Nerz (mink)	1	705 ms	einst (once)	21	660 ms
	Alm (alp)	1	505 ms	bloß (mere)	86	595 ms
				nebst (together with)	5	701 ms

Note. freq., frequency of usage.

Table 2. Experimental design

			Standard word			
			Noun		function word	
			high	Low	high	low
Deviant word	noun	high	+	+	+	-
		low	+	+	-	+
	function word	high	+	-	+	+
		low	-	+	+	+

Note. high, high frequency of usage; low, low frequency of usage

Figure Captions

Figure 1

Comparisons of physically identical stimuli. Deviant-minus-Standard difference waves shown separately for the four main deviant categories (noun vs. function word × low vs. high frequency of usage). Data re-referenced to linked mastoids. In the figures showing ERPs, red and blue lines correspond to function words and nouns, respectively; continuous and dashed lines correspond to high and low frequency of usage, respectively.

Figure 2

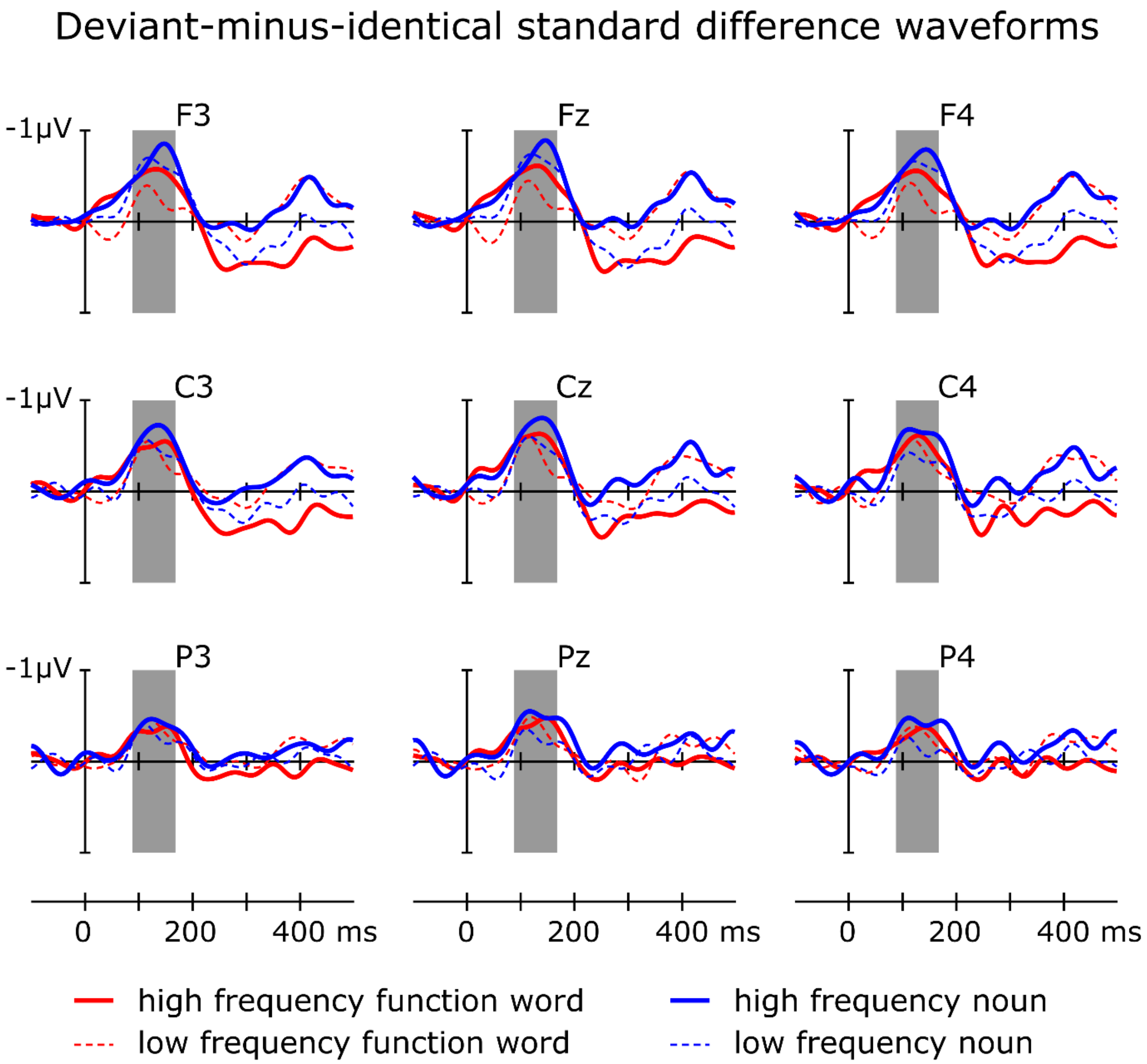
MMN amplitudes shown for the four main deviant categories (noun vs. function word × low vs. high frequency of usage). Data re-referenced to linked mastoids.

Figure 3

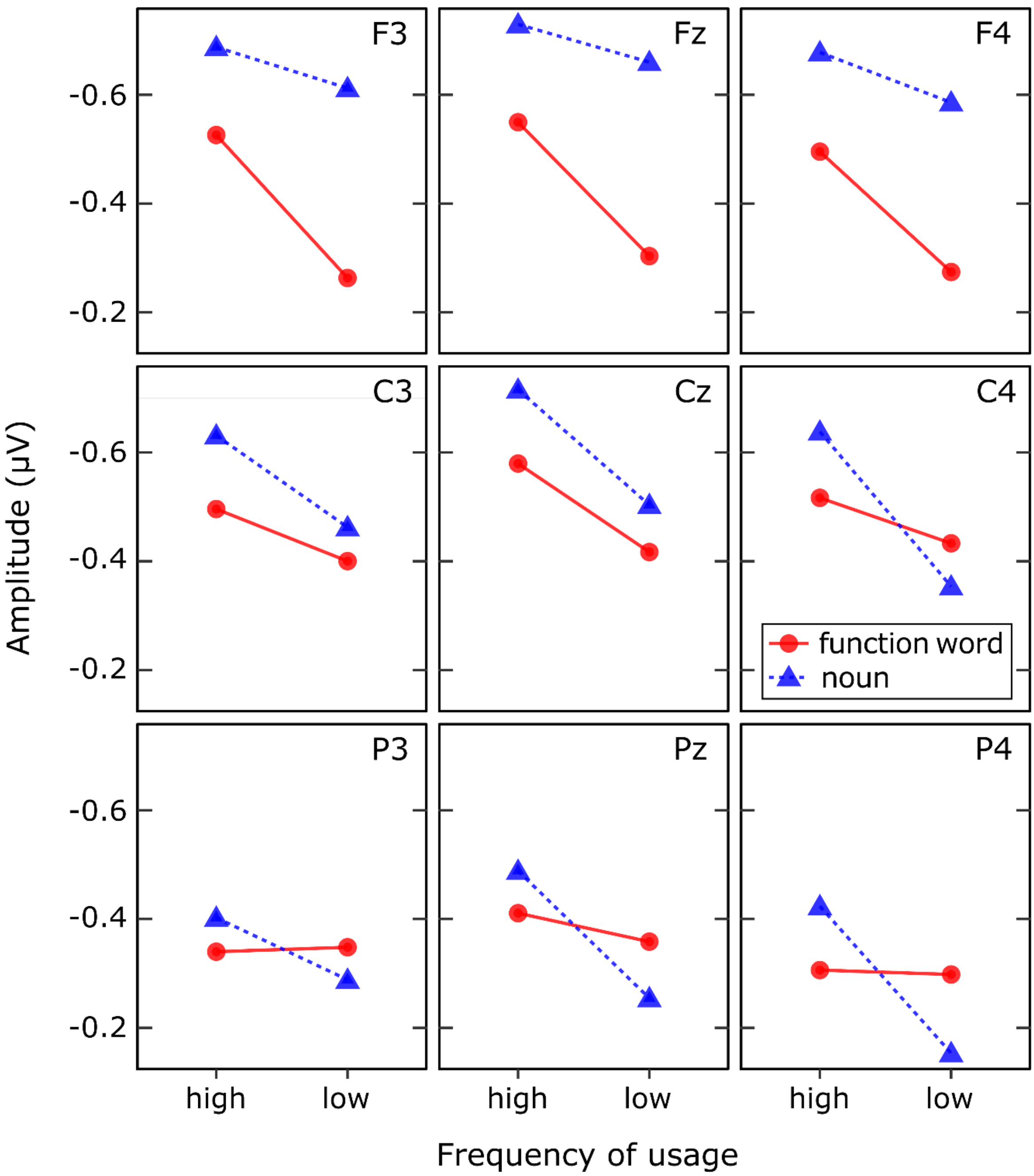
ERPs elicited by deviants in the context of different word classes. Data re-referenced to linked mastoids.

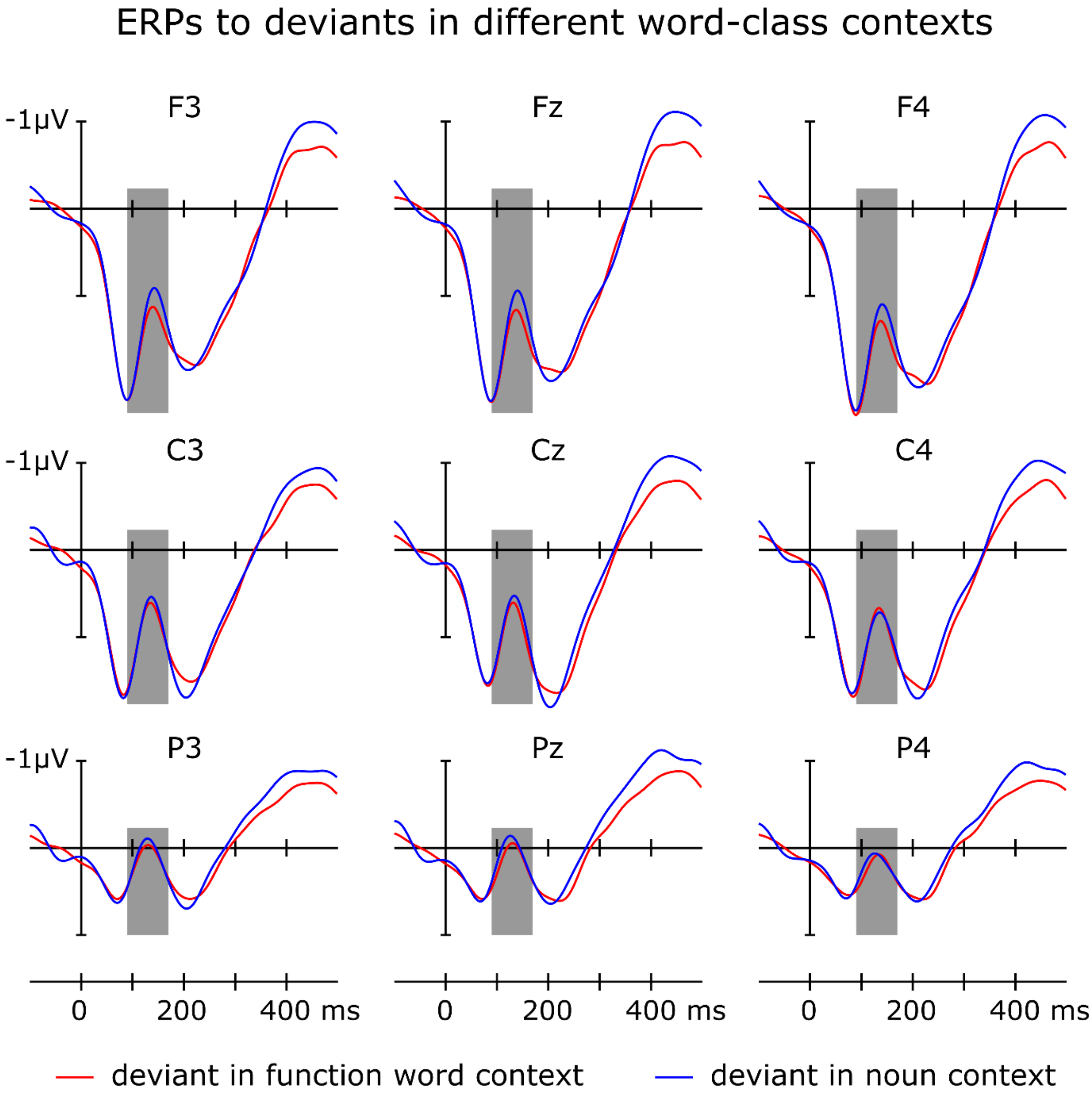
Figure 4

ERPs elicited by deviants in the context of high- and low frequency words. Data re-referenced to linked mastoids.

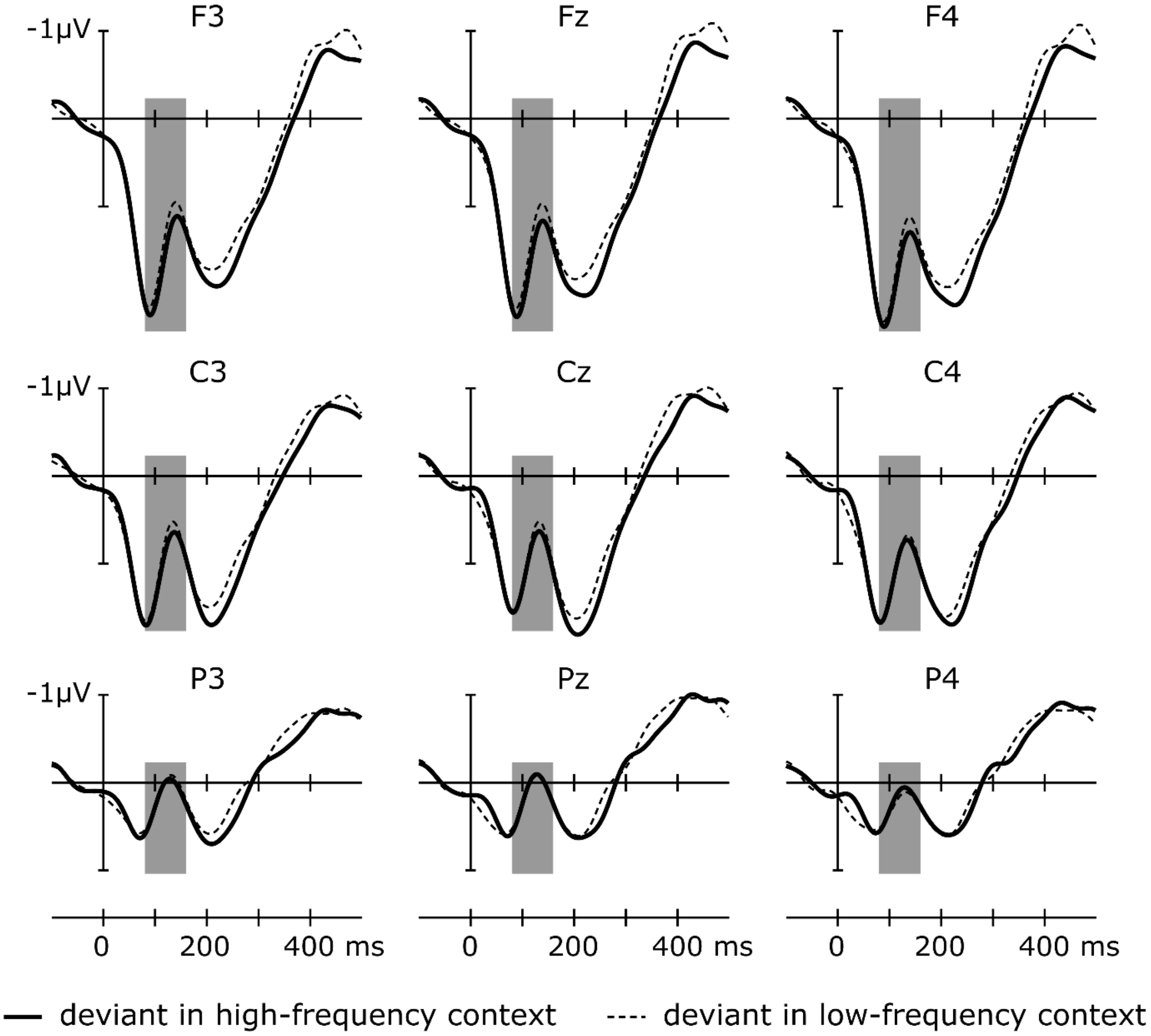


Deviant-minus-identical standard difference waveforms
-1µV
F3
Fz
F4
-1µV
C3
Cz
C4
-1µV
P3
Pz
P4
0
200
400 ms
0
200
400 ms
0
200
400 ms
high frequency function word
low frequency function word
high frequency noun
low frequency noun


F3
Fz
F4
C3
Cz
C4
P3
Pz
P4
-0.6
-0.4
-0.2
Amplitude (µV)
function word
noun
high
low
Frequency of usage


ERPs to deviants in different word-class contexts
-1µV
F3
Fz
F4
-1µV
C3
Cz
C4
-1µV
P3
Pz
P4
0
200
400 ms
0
200
400 ms
0
200
400 ms
deviant in function word context
deviant in noun context

ERPs to deviants in different frequency-of-usage contexts



Supplementary Material

Stimulus Material. For each of the 16 word items, five exemplars uttered by different female native speakers of German were used. Measurements of the fundamental frequencies (median F0) of the stimuli using Praat (Boersma & Weenink, 2020). For each stimulus .wav file the F0 contour was calculated by Praat, the median F0 was taken from the contour points of the respective .wav file. And each of the 80 .wav files was then characterized by the median F0.