

Familiarity Affects the Processing of Task-irrelevant Auditory Deviance

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Abstract

■ The effects of familiarity on auditory change detection on the basis of auditory sensory memory representations were investigated by presenting oddball sequences of sounds while participants ignored the auditory stimuli. Stimulus sequences were composed of sounds that were familiar and sounds that were made unfamiliar by playing the same sounds backward. 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. We found an enhancement in detecting changes when deviant sounds appeared among familiar standard sounds compared when they were delivered among unfamiliar standards. Familiarity with the deviant sounds also enhanced the change-detection process. We suggest that tuning to familiar items sets up preparatory processes that affect change detection in familiar sound sequences. ■

INTRODUCTION

Deviance in auditory stimulation is often detected even if the sounds are task-irrelevant and ignored. The deviance detection process is known to be affected both by the auditory sensory and categorical representations of the sounds involved in forming an auditory regularity or violating one. Previous research on speech processing has shown that the deviance detection process may be modulated by the lexical status of the regular and irregular items (Jacobsen et al., 2004; Shtyrov & Pulvermüller, 2002a, 2002b; Pulvermüller et al., 2001). Jacobsen et al. (2004) showed that words set up a different context than pseudowords for the detection of auditory deviance, and Pulvermüller et al. (2001) found stronger deviance detection for meaningful than for meaningless deviant speech stimuli. The present work addresses the question whether these effects are linguistic in nature or whether familiar versus unfamiliar nonspeech items also show similar effects. The answer to this question may demonstrate the role of long-term learning in sensory stimulus processing as well as constraining theories of lexical processing.

Some cognitive processing of sounds occurs even when one performs an unrelated task (i.e., the sounds are not relevant for current behavior). Detection of differences between the current auditory event and the auditory stimulus representation(s) extrapolated from the regularities that have been extracted from the

preceding auditory stimulation (termed the representation of the standard) is one of the operations performed irrespective of the relevance of sounds. The outcome of this deviance detection process is reflected by the mismatch negativity (MMN) event-related brain potential (ERP) component and its magnetic counterpart, the MMNm (for recent reviews, see Picton, Alain, Otten, Ritter, & Achim, 2000; Näätänen & Winkler, 1999). Using the ERP technique allows one to assess auditory processing with millisecond accuracy and, in some cases, without the interference of task-related operations and participant strategies. 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 Sussman, Winkler, & Wang, 2003; Näätänen, 1992). Deviation from various simple, complex, and even abstract auditory regularities has been shown to elicit MMN (for a review, see Näätänen, Tervaniemi, Sussman, Paavilainen, & Winkler, 2001). Thus, the MMN can be used to study what auditory regularities have been detected by “default” in the auditory system (i.e., when the sounds are not in the focus of attention) and, by way of assessing the detected regularities, what kinds of analyses have been performed on task-irrelevant sounds.

The electrically recordable MMN component appears as a negative deflection in the ERP, reaching its peak between 100 and 250 msec from the onset of the deviation. It shows a maximal (negative) amplitude over fronto-central scalp areas usually appearing with reversed polarity at electrodes positioned over the opposite side of the Sylvian fissure, such as the mastoid leads (e.g.,

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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).

With the current experiment, we studied a contextual effect on the detection of task-irrelevant changes as reflected by the MMN component. Previous studies have found that the immediate auditory context can affect the elicitation and parameters of the MMN component. For example, Sussman, Sheridan, Kreuzer, and Winkler (2003) investigated the effects of the relative probability of sounds in an oddball sequence, searching for the critical factors influencing the representation of the standard. Using different proportional within-sequence relationships of three different sounds, the authors found that the standard or standards are not established on the basis of relative probability, rather “they emerge as a result of global characteristics, the longer-term context, of the sound sequence” (p. 465, Abstract). Winkler, Sussman, et al. (2003) conducted two sets of experiments in which the features of contextual tones were varied, creating two different auditory contexts. They observed a close correspondence between effects of auditory context on behavioral measures of auditory grouping and the elicitation of the MMN response. These results, as well as some others (e.g., Sussman & Winkler, 2001; Winkler, Schröger, & Cowan, 2001) suggest that a large part of contextual processing may occur even when the sounds are not relevant for the subject’s task (see also below, Jacobsen et al., 2004).

The effects of the context on the processing of a given sequence of sounds is also 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 in familiar contexts (e.g., van Zuijen, Sussman, Winkler, Näätänen, & Tervaniemi, 2004; Brattico, Näätänen, & Tervaniemi, 2002; for a review, see Schröger, Tervaniemi, & Huotilainen, 2004). Under experimental conditions, training with unfamiliar sounds resulted not only in improved active discrimination, but also in detecting changes in passive situations hours, days (e.g., Atienza & Cantero, 2001; Huotilainen, Kujala, & Alku, 2001; Näätänen, Schröger, Karakas, Tervaniemi, & Paavilainen, 1993), or even months (Kraus, McGee, Carrell, & Sharma, 1995) after the original training session. Similarly to the above examples from music, learned, 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 of Hungarian and Finnish, Winkler,

Lehtokoski, et al. (1999) 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 Phillips et al., 2000; Sharma & Dorman, 2000; Dehaene-Lambertz, 1997; Näätänen, Lehtokoski, et al., 1997). These results suggest that linguistic information triggers additional processes, which may 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”; Aaltonen, Eerola, Hellstrom, Uusipaikka, & Lang, 1997; Kuhl, 1991), language training (Winkler, Kujala, Tiitinen, et al., 1999; Kraus et al., 1995), and language development (Cheour et al., 1998). The default detection of speech-specific deviations suggests language-specific processing of the task-irrelevant speech sounds.

Among the contextual effects on MMN, some have been assumed to stem from lexical analysis of task-irrelevant speech sounds. Basing on their EEG and MEG results, Pulvermüller and his colleagues (Shtyrov & Pulvermüller, 2002a, 2002b; Pulvermüller et al., 2001; for a review, see Pulvermüller, 2001) suggested that task-irrelevant words undergo lexical analysis. In their first EEG experiments (Pulvermüller et al., 2001), a word and a pseudoword deviant were infrequently presented within the repetitive sequence of a pseudoword standard. The MMN responses elicited by the two types of deviants were compared with each other. In the corresponding MEG experiment (Pulvermüller et al., 2001), isolated syllables were presented in random succession at a 450-msec stimulus onset asynchrony. On 16% of the trials, a succession of two of these syllables resulted either in a word or a pseudoword deviant. The MMN responses elicited by the codas completing a word versus a pseudoword deviant were compared with each other. In all of these experiments, larger MMNs were elicited by word deviants than by pseudoword deviants. The authors interpreted their results as reflecting the “presence of memory traces for individual spoken words in the human brain” (p. 607, Abstract). It should be noted that the results of Pulvermüller et al. showing higher-amplitude MMN for word than for pseudoword deviants appear to contradict the results of Diesch, Biermann, and Luce (1998). Further, Winkler, Kujala, Alku, et al. (2003) found no difference between the MMNs elicited by the same word contrast when the two words had the same or two different meanings (as a result of a change in the language context). This result is at odds with the hypothesis that the specific meaning of the standard and deviant speech sounds affect the deviance detection process reflected by MMN, but it does not

contradict the hypothesis that lexical analysis per se would affect MMN.

Recently, we reported a cross-language study on the processing of lexicality with Hungarian and German participants (Jacobsen et al., 2004). In our study, stimulus sequences were composed of words that were language-familiar, lexical, and meaningful in Hungarian but language-unfamiliar, not lexical, and meaningless, but phonotactically legal in German, and words with the opposite characteristics. 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. However, we observed higher MMN amplitudes when the standard was language-familiar versus when it was not. In contrast, the lexical status of the deviant had no significant effect on the MMN response.

On the basis of these results, we suggested that either the lexical status of, or the subject’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 previous study could not distinguish between these two possibilities (lexical status and familiarity). 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 subjects’ 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 nonspeech stimuli, when the familiarity of the standard and deviant items is manipulated. The current experiment tested this possibility.

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 auditory material, this distinction is supported, among others, by results showing changes in the MMN responses measured immediately after learning a difficult auditory discrimination and following periods of sleep (Atienza, Cantero, & Stickgold, 2004; Atienza & Cantero, 2001).

Few studies have previously investigated the processing of sounds varying in familiarity. Cycowicz and Friedman (1998) asked participants to detect infrequent oddball tones that were presented among frequent standard tones. In addition to the target tones, task-irrelevant novel sounds were infrequently interspersed in the sequence. (Note that all sounds were attended, but the novel sounds did not require a response from the subject.) Novel sounds elicited the novelty P3 ERP response, reflecting attentional orienting towards these unexpected events. The novel sounds were either familiar or unfamiliar environmental sounds (the familiarity of the sounds was established prior to the EEG experiment). Upon repetition of the familiar sounds, an attenuation of the novelty P3 was observed, which was taken to reflect habituation. No attenuation of the novelty P3 was found for the unfamiliar sounds, suggesting that habituation of the response to unfamiliar sounds requires longer time and/or more exposure.

The present study addressed the question whether the standard context effect on MMN obtained by Jacobsen et al. (2004) was specific to speech stimuli or whether it should be considered a familiarity context effect of more general nature. To this end, familiar and unfamiliar nonspeech sounds were presented in oddball blocks to participants who ignored the auditory stimulation while watching a silent subtitled movie. Two familiar sounds were used: “breaking dishes” and the Microsoft Windows chime signal. Their unfamiliar counterparts were created by reversing familiar sounds, that is, by playing the same sounds backwards. These stimuli were presented in oddball blocks in a fully crossed design: familiar standard with familiar deviant, familiar standard with unfamiliar deviant, unfamiliar standard with familiar deviant, unfamiliar standard with unfamiliar deviant. In addition, in one control stimulus block, the four stimuli were presented equiprobably. The equiprobable control served as comparison for the various deviant stimuli by (1) presenting the same physical stimuli (2) approximately the same number of times as the deviants and (3) within a context in which familiar and unfamiliar items appeared with equal probability. Thus, throughout the study, MMN responses were estimated by subtracting from a given deviant response the response elicited by the same stimulus within the equiprobable control condition. The overall design allowed us to compare between responses elicited by deviants (all four of them) when they appeared in a familiar versus unfamiliar context. The design also allowed comparing between the ERPs elicited by familiar versus unfamiliar deviants, although for this test we could only compare responses elicited by acoustically different stimuli. (However, note that primary effects of the acoustic difference are reduced by always subtracting from the deviant ERP the response elicited by the same stimulus in the control condition.)

Two hypotheses put forward by previous studies were tested. The main hypothesis was derived from our previous result showing that a familiar language context enhances the processes of deviance detection (Jacobsen et al., 2004; see Introduction). Applying this notion to the present experiment, one should expect that a sound environment containing mostly familiar sounds sets up a different context than the repetition of unfamiliar sounds does. The familiar context hypothesis then suggests MMNs of higher amplitude to be elicited by deviants appearing in the familiar as compared to the unfamiliar context, irrespective of the level of familiarity of the deviant item. Additionally, it is possible that familiar deviants also elicit an MMN of higher amplitude than unfamiliar ones. This latter hypothesis is a generalized extension of the lexical trace hypothesis, which predicts that deviants that are represented in the mental lexicon elicit a higher-amplitude MMN than deviants that are not. With regard to the lexical trace hypothesis, no effects should be found in the current study because we do not use speech stimuli or stimuli that correspond to a single unique item in the lexicon.

RESULTS

Effects of the Familiarity of the Standard Stimuli on the MMN

The grand-average ERPs shown in Figure 1 are all based on aggregations of all four stimuli and only the context

differs. In other words, the deviant ERPs were collapsed across all four stimuli, collected from those stimulus blocks, in which the stimuli took the role of deviants. This was done separately for sequences with familiar standards (familiar condition) and unfamiliar standards (unfamiliar condition). The control ERP was also collapsed across the same four stimuli, collected from the equiprobable condition. Therefore, the figure compares the responses elicited by deviant sounds in the context of familiar standards and unfamiliar standards with the average ERP elicited in the separate equiprobable condition (each response in this comparison has been collapsed across the four stimuli).

The MMNs shown in Figure 2 were derived by subtracting the equiprobable-condition ERP from the deviant ERPs, one from the familiar context and the other from the unfamiliar context. Difference waves were based on data re-referenced to linked mastoids.

As was expected, MMN was obtained for both contexts (the familiar- and unfamiliar-standard conditions). The results of a repeated-measures ANOVA [factors: Stimulus (deviant vs. control) \times Familiarity (familiar vs. unfamiliar) \times Electrode position: anterior–posterior (F vs. C vs. P lines, cf. International 10–20 system) \times Electrode position: laterality (left vs. middle vs. right)] are given in Table 1. There were higher frontal than parietal MMN amplitudes. This well-known MMN scalp topography caused an interaction between the Stimulus and Electrode (anterior–posterior) factors. Because there were no effects of laterality, the other effects were

Figure 1. Grand-averaged ERP responses elicited by deviants (collapsed across all four stimuli) in the context of familiar (thick line) and unfamiliar (dashed line) standard stimuli together with the control ERP (thin line; also collapsed across all four stimuli). All measured electrode sites are shown. Scales are in milliseconds and microvolts.

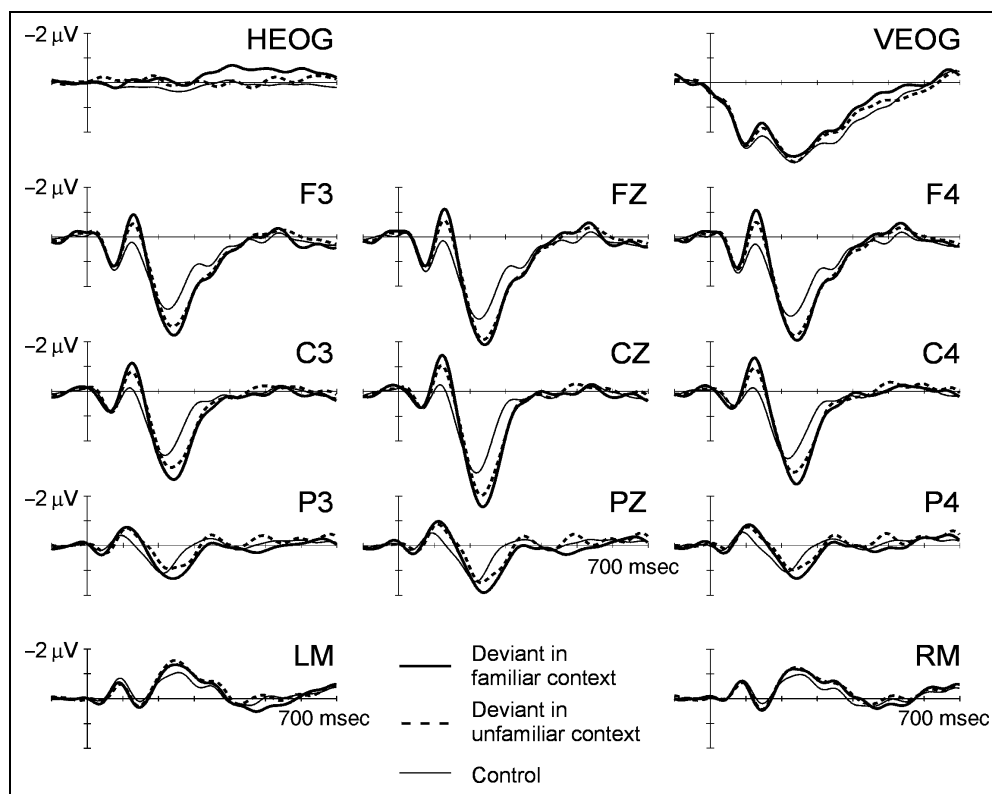
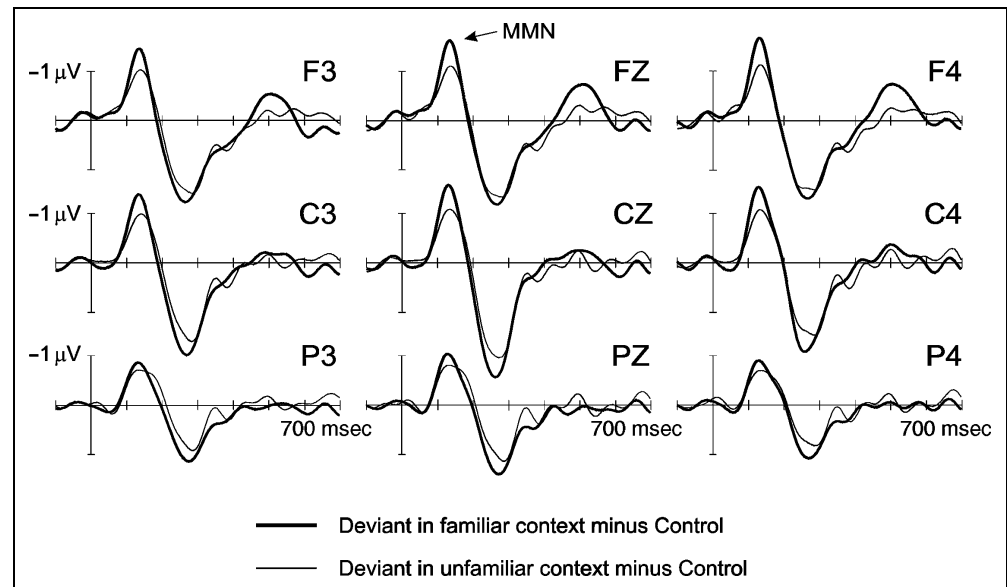


Figure 2. Grand-averaged deviant-minus-control difference waves obtained in the familiar (thick line) and the unfamiliar contexts (thin line). ERPs were re-referenced to averaged mastoids to display the full MMN response. Scales are in milliseconds and microvolts.



further investigated for electrode Fz, where MMN appeared with highest amplitude along the midline. Significant main effects were found for Stimulus type [the presence of MMN: $F(1,20) = 88.52, p < .01$] and Familiarity [$F(1,20) = 5.35, p < .05$], and a significant interaction between Stimulus type and Familiarity [$F(1,20) = 5.35, p < .05$], the two latter results representing that MMN had a higher amplitude for deviants in the familiar than in the unfamiliar context. (Note that because the control ERP response was common for the two familiarity conditions, the main effect of familiarity and the interaction basically reflects the same effect.)

Effects of the Familiarity of the Deviant Stimuli on the MMN

The grand-average ERPs shown in Figure 3 are based on separate aggregations of the familiar and the unfamiliar sounds when these served as deviants in the oddball stimulus blocks compared with the responses elicited by the same sounds in the control (equiprobable) condition. The ERPs collapse deviant sounds that appeared in the context of familiar and unfamiliar standards.

The difference waves shown in Figure 4 were calculated as follows. The ERP to the familiar sounds in the equiprobable condition was subtracted from the familiar deviant-stimulus ERP, the latter being averaged across the familiar and the unfamiliar contexts. The ERP elicited by unfamiliar sounds in the equiprobable condition was subtracted from the unfamiliar deviant-stimulus ERP, again averaged across the familiar and the unfamiliar contexts. In these difference waves, signals have been re-referenced to the linked mastoids.

MMN was obtained for both familiar and unfamiliar deviant sounds. The results of the omnibus repeated-

measures ANOVA are given in Table 2 (see the ANOVA structure above, familiarity denotes the familiarity status of the deviant stimulus in the current ANOVA). The interaction between the Familiarity and the Electrode factors may have stemmed from stimulus differences, that is, differential processing of familiar versus unfamiliar sounds per se. As this effect was not related to MMN (only interactions with the Stimulus factor are related to the MMN scalp topography), it was not further investigated here. Furthermore, because the MMN scalp topography (higher frontal than parietal MMN amplitudes) caused an interaction between the Stimulus and Electrode factors, the remaining effects were further investigated for electrode Fz, where MMN is expected to appear with high amplitude. There was a main effect of Stimulus type [the presence of MMN: $F(1,20) = 80.76, p < .01$], and a significant interaction between Stimulus type and Familiarity [$F(1,20) = 6.58, p < .05$], the latter reflecting the higher MMN amplitudes elicited by familiar as compared to unfamiliar deviants.

DISCUSSION

The present study revealed an effect of the familiarity of the context on the processing of auditory deviance in oddball sequences of task-irrelevant sounds. Deviant nonspeech sounds elicited MMN with a higher amplitude when they appeared within the repetitive sequence of a familiar as opposed to an unfamiliar nonspeech sound. (Note that because the MMN responses for the familiar and unfamiliar context conditions were obtained from the same sounds presented with the same sequential probabilities, this result cannot be explained on the basis of acoustical or

Table 1. Repeated-measures ANOVA for Both Contexts (Familiar- and Unfamiliar-standard Conditions)

Source	<i>F</i>	<i>G-G-Epsilon</i>	<i>p</i>
Stimulus (Deviant vs. Control)	92.57	–	.01
Familiarity (Familiar vs. Unfamiliar)	3.32	–	.08
Electrode position			
Anterior–posterior (F, C, P)	1.17	0.57	.29
Laterality (left, middle, right)	0.37	0.95	.68
Stimulus × Familiarity	3.32	–	.08
Stimulus × Electrode position— anterior–posterior	12.45	0.61	.01
Stimulus × Electrode position— laterality	2.17	0.73	.14
Familiarity × Electrode position— anterior–posterior	3.66	0.68	.05
Familiarity × Electrode position— laterality	0.46	0.81	.60
Electrode position—anterior– posterior × Electrode position—laterality	1.34	0.75	.27
Stimulus × Familiarity × Electrode position—anterior–posterior	3.66	0.68	.05
Stimulus × Familiarity × Electrode position—laterality	0.46	0.81	.60
Stimulus × Electrode position— anterior–posterior × Electrode position—laterality	1.88	0.72	.15
Familiarity × Electrode position— anterior–posterior × Electrode position—laterality	0.28	0.81	.85
Stimulus × Familiarity × Electrode position—anterior–posterior × Electrode position—laterality	0.28	0.81	.85

Adjusted *p* values are reported. .01 denotes *p* values smaller than .01.

refractoriness-related differences.) Our previous study (Jacobsen et al., 2004) obtained a comparable effect for spoken words compared with pseudowords. The present results indicate that this effect is not limited to linguistic processing. Rather, it appears to reflect a more general feature of auditory processing: Familiarity of the auditory context enhances deviance detection. Familiar context (standard) may help deviance detection (reflected by the MMN response) by providing a more precise and more detailed representation of the regular item compared with the representation of unfamiliar standard stimuli. As a consequence, more specific and/or more reliable sensory inferences are afforded on the basis of the more elaborate sensory memory representations in familiar as opposed

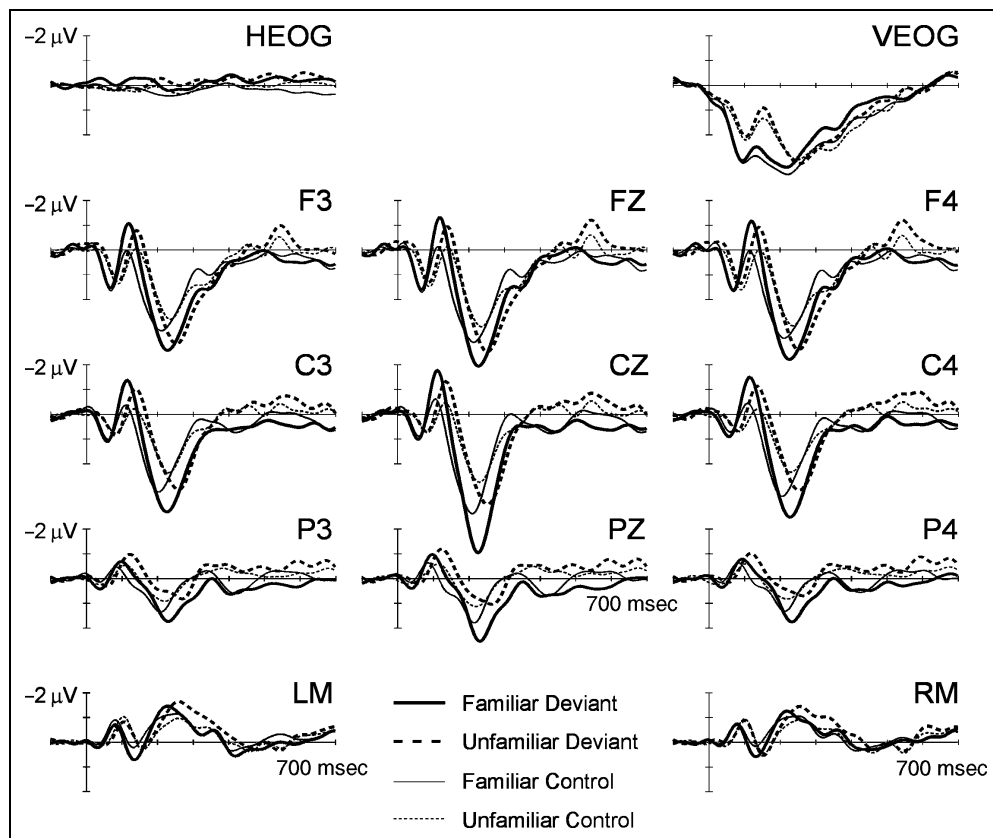
to unfamiliar contexts. This, in turn, renders the deviant to stand out more, resulting in the elicitation of higher-amplitude MMN responses in familiar than in unfamiliar contexts. The conclusion that common mechanisms may operate on linguistic and nonlinguistic auditory processing is also supported by recent evidence from voxel-based lesion to symptom mapping, suggesting that verbal and nonverbal auditory information are processed in highly overlapping auditory cortical structures (Saygin, Dick, Wilson, Dronkers, & Bates, 2003).

We found that a familiar (learned) context affects sensory processing of sounds encountered in this context even when the sounds are not relevant for the ongoing activity. This suggests that long-term memory is consulted in processing task-irrelevant sounds (for similar conclusions, see Näätänen, Tervaniemi, et al., 2001) and, further, that learning the details of a given context affects how we perceive events within this context. Thus, our personal history affects our perception in most everyday life situation.

In our previous study (Jacobsen et al., 2004), we did not find a significant effect of the lexical status of the deviants on the MMN amplitude (see, however, Pulvermüller et al., 2001). That is, words did not elicit significantly higher-amplitude MMNs than pseudowords, although the MMN amplitudes were numerically higher for familiar than unfamiliar deviants. In the present study, however, an effect of familiarity of the deviant stimulus was obtained. Because the current experiment presented nonlinguistic stimuli, the results indicate that the effect of the familiarity of the deviant stimulus may not be specific for linguistic processing. Rather, it appears to reflect the more general processes related to familiarity. There is, however, reason for caution with respect to the interpretation of the results regarding the effect of the familiarity of deviants. Although the MMNs for familiar and unfamiliar deviants (see Figure 4) were derived by subtracting responses elicited by the same stimuli, the MMN responses for familiar and unfamiliar sounds were elicited by acoustically different stimuli. As a consequence, the confound from acoustical differences cannot be completely ruled out. This means that the higher MMN amplitudes found for familiar as opposed to unfamiliar deviants may have been a consequence of the specific acoustic stimulus features rather than of familiarity itself. However, because previous studies (e.g., Pulvermüller et al., 2001) found a similar effect using identical stimulus material, the familiarity interpretation of the current results is probably correct.

One issue regarding the effects of familiarity on auditory change detection has been left open by the current as well as by previous studies. The familiar stimuli of the present study were meaningful items. For example, the sound of breaking dishes appears to have elicited involuntary shifts of attention even after

Figure 3. Grand-averaged ERP responses elicited by familiar (thick continuous line, collapsed across the two familiar stimuli and familiar and unfamiliar standards) and unfamiliar deviants (thick dashed line) together with the respective control-condition responses (thin lines, solid and dashed collapsed between the familiar and unfamiliar sounds, respectively). All measured electrode sites are shown. Scales are in milliseconds and microvolts.



several presentations. In contrast, the unfamiliar stimuli were meaningless (e.g., the reversed dish-breaking sound did not elicit attention shift after its novelty wore out). Thus, we cannot tell whether the observed familiarity effect(s) on auditory change detection requires that the items have assigned meanings in long-term memory or whether the existence of a well-learned

sensory stimulus representation (irrespective of whether the item is meaningful or not) is a sufficient prerequisite of the familiarity effect(s). This issue requires further studying using different methods, because familiar sounds usually have assigned meaning (even if it is unique to the person). It is, however, an important question, the answer to which would further specify

Figure 4. Grand-averaged deviant-minus-control difference waves obtained for familiar (thick line) and unfamiliar deviants (thin line). ERPs were re-referenced to averaged mastoids to display the full MMN response. Scales are in milliseconds and microvolts.

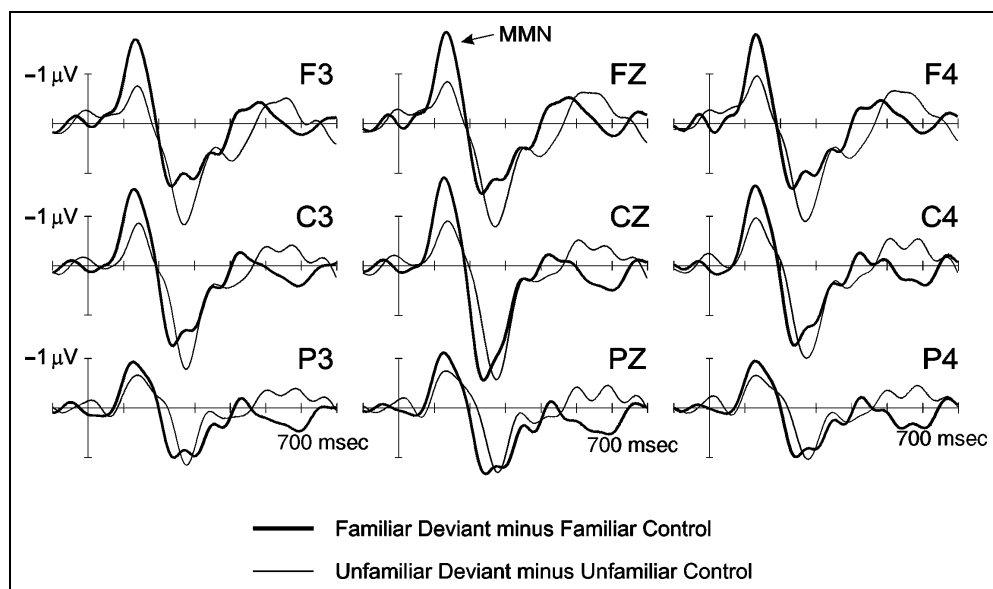


Table 2. Repeated-measures ANOVA for Both Deviant Types (Familiar- and Unfamiliar-deviant Conditions)

Source	<i>F</i>	<i>G-G-Epsilon</i>	<i>p</i>
Stimulus (Deviant vs. Control)	81.30	–	.01
Familiarity (Familiar vs. Unfamiliar)	0.61	–	.44
Electrode position			
Anterior–posterior (F, C, P)	1.23	0.57	.29
Laterality (left, middle, right)	0.37	0.96	.69
Stimulus × Familiarity	4.72	–	.04
Stimulus × Electrode position— anterior–posterior	12.82	0.63	.01
Stimulus × Electrode position— laterality	2.25	0.73	.13
Familiarity × Electrode position— anterior–posterior	0.42	0.64	.57
Familiarity × Electrode position— laterality	10.69	0.94	.03
Electrode position—anterior– posterior × Electrode position—laterality	1.35	0.76	.27
Stimulus × Familiarity × Electrode position—anterior–posterior	4.74	0.59	.03
Stimulus × Familiarity × Electrode position—laterality	1.01	0.69	.35
Stimulus × Electrode position— anterior–posterior × Electrode position—laterality	1.77	0.73	.16
Familiarity × Electrode position— anterior–posterior × Electrode position—laterality	9.09	0.84	.01
Stimulus × Familiarity × Electrode position—anterior–posterior × Electrode position—laterality	0.85	0.59	.45

Adjusted *p* values are reported. .01 denotes *p* values smaller than .01.

the role of meaning in processing linguistic and nonlinear information.

METHODS

Participants

Twenty-one volunteers participated in the study (6 men and 15 women). The median age was 22 years (range 18–38). All participants were students of the University of Leipzig. They reported normal auditory and normal or corrected-to-normal visual acuity. They gave informed consent, and received course credit or monetary compensation.

Materials

Four stimuli were used. There were two familiar sounds: breaking dishes and the Microsoft Windows chime sound. Unfamiliar sounds were created by playing these sounds backwards. Stimuli were 613 msec long with rise and fall times of 8 msec each (Hann window). Stimuli were presented binaurally via headphones (Sennheiser HD 25) with a stimulus onset-to-onset interval of 1500 msec at 65 dB (SPL) intensity level (HMS III, Head Acoustics, Aachen, Germany).

Procedure

Participants were seated comfortably in an electrically shielded and sound-attenuated experimental chamber (International Acoustic Company, Niederkrüchten, Germany) and were instructed to ignore the auditory stimulation while watching a silent subtitled movie. All subjects reported that they could ignore the sounds. Informal questioning of the participants revealed that they perceived the familiar sounds as familiar and the unfamiliar sounds as unfamiliar.

In the experimental conditions, oddball stimulus sequences were presented. In each such sequence, one sound served as the standard (85% of the trials) and another as the deviant (15% of the trials), delivered in a pseudorandomized order forcing at least two standards to be presented between successive deviants. In separate stimulus blocks (600 trials, each), all possible pairs of the four test sounds were tested (also taking into account the two possible roles: standard or deviant). In the control condition, the four stimuli were presented 100 times, each equiprobably in a pseudorandomized order preventing stimulus repetitions. The order of stimulus blocks was counterbalanced across participants. The experiment was divided into two sessions. Control stimulus blocks were delivered in the middle of both sessions. Experimental sessions lasted approximately 2 hr including data acquisition, electrode application, and removal.

Electrophysiological Recordings

The electroencephalogram (EEG; Ag/AgCl electrodes, Falk Minow Services, NeuroScan SynAmps EEG amplifier; NeuroScan Acquire) was recorded continuously (16-bit resolution, 500-Hz sampling rate) with the common reference attached to the nose (ground at FPz) from nine standard (international 10–20 system) scalp locations (F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4) and both mastoids (Lm and Rm). 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 5kΩ. On-line filtering

was carried out using a 0.05 Hz high-pass and 70 Hz low-pass filter.

Data Analysis

EEG signals were off-line band-pass filtered with a finite impulse response filter: 1601 points, critical frequencies of 1 Hz (high-pass) and 15 Hz (low-pass). EEG epochs of 800 msec length, including a 100-msec prestimulus baseline, were averaged separately for each condition, stimulus, and participant (EEP 3.0 software; MPI-CNS, ANT software). Single-sweep ERPs showing an amplitude change exceeding 100 μV at any of the recording channels were excluded from averaging. Grand averages were subsequently computed from the individual-subject averages. Difference waves were computed by subtracting the ERPs elicited by a given stimulus (or group of stimuli) in the equiprobable control condition from the response elicited by the same stimulus (or stimulus group) when it served as deviant. For ERP quantification, amplitudes were measured as the mean voltage in a uniform 20-msec window centered on the respective grand-average MMN peak latency measured from the corresponding deviant-minus-control difference wave that was re-referenced to linked mastoids. This measurement strategy takes into the MMN scalp distribution and generator structure as described in the Introduction (e.g., Schröger, 1998). MMN amplitude effects were assessed with repeated-measures analyses of variance. Where applicable, Greenhouse–Geisser (G-G) corrected degrees of freedom were used and G-G epsilon values are reported.

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