ISSN 0362-1197, Human Physiology, 2017, Vol. 43, No. 4, pp. 395–403. © Pleiades Publishing, Inc., 2017.
Original Russian Text © A.A. Aleksandrov, K.S. Memetova, L.N. Stankevich, 2017, published in Fiziologiya Cheloveka, 2017, Vol. 43, No. 4, pp. 47–56.

Lexical Context Affects Mismatch Negativity Caused by Pseudowords

A. A. Aleksandrov, K. S. Memetova*, and L. N. Stankevich

St. Petersburg State University, St. Petersburg, 199034 Russia

**e-mail: k.memetova@spbu.ru*

Received April 5, 2016

Abstract—The aim of this study was to investigate the effect of lexical context on the latency and the amplitude of the mismatch negativity (MMN) brain potential caused by perception of pseudowords. The event-related potentials were recorded according to the multideviant passive odd-ball paradigm by using only pseudowords (control condition) or pseudowords with Russian words with different lexical frequencies (lexical context). It was found that different MMN patterns were generated when the same pseudoword was presented in different contexts. Pseudoword presentation in a context with other pseudowords resulted in a relatively small amplitude and large latency of MMN. If the same pseudoword was presented in a context with words, it induced significantly increased amplitude and reduced latency of MMN varying in the range of 100–200 ms. It is supposed that the pseudoword presented in a context with words is perceived as conceptually different stimulus, which leads to a significant increase in MMN. Moreover, our findings support the hypothesis that MMN is affected by lexical frequency. In particular, presentation of a high-frequency word induced a significantly more pronounced MMN response than a low-frequency one. High-frequency words also evoked earlier response, which indicates more rapid access to a frequently used lexical entry. More frequent use of certain words results in stronger internal connections in the corresponding memory circuit, which in turn is determined by the lexical context. We hypothesize that different intensities of activation depends on the strength of lexical representation.

Keywords: event-related potentials (ERP), pseudowords, word frequency, mismatch negativity (MMN), words, language, attention

DOI: 10.1134/S036211971704003X

An important issue of modern psychophysiology are questions concerning the mechanisms governing the perception and processing of speech and language, as well as the representation of words in the mental lexicon. An informative method of studying psychophysiological mechanisms of speech is the analysis of event-related potentials. This type of research is now making growing use of the mismatch negativity (MMN) component of auditory event-related potentials (ERPs), which is generated not only in response to purely acoustic differences of stimuli, but also in response to changes in their abstract properties, including linguistic differences (MMN response to differing phonemes, syllables, or words).

It still remains largely unclear how linguistic differences affect the recorded MMN. The first data on MMN responses to linguistically different stimuli were obtained by Näätänen et al. using the material of Finnish and Estonian languages [1]. The authors showed that speech perception depended on two simultaneously acting mechanisms: (1) detection of acoustic changes involving both brain hemispheres and (2) detection of phonemic changes involving primarily the left hemisphere. Our previous study employing the passive odd-ball paradigm [2] showed for the first time that word frequency affected the pattern of auditory MMN. In particular, the auditory MMN caused by presentation of high-frequency words had higher amplitudes and lower latency than the MMN induced by low-frequency words. Supposedly, this phenomenon is related to the activation of the representations of the corresponding words, while the frequency of usage of lexical entries affects neuronal connections. Further studies compared MMN patterns caused by well-known and novel words (neologisms or rare terminology) and also revealed a difference in responses, e.g., novel words caused MMN with lower amplitudes and latencies lying in later periods of time [3, 4].

Analysis of ERP patterns in word perception often employs pseudowords as stimuli lacking lexical representations in the mental lexicon in order to reveal the role of word meaning, lexical category, or the frequency of usage on ERP characteristics, as well as to control the possible effect of acoustic differences.

Our previous study showed that MMN induced by pseudowords differed in its latency and amplitude from MMN induced by real words [5]. These results invite the hypothesis that identification of a stimulus as a pseudoword causes a specific reaction, as

Table 1. Russian phonemes and their properties

Phonetic traits	[sh]	[zh]	[s]	[k]	[n]
Hard	+	+	+	+	+
Voiced	–	+	–	–	–
Voiceless	+	–	+	+	–
Sonorous	–	–	–	–	+
Stop	–	–	–	+	+
Fricative	+	+	+	–	–
Dental	–	–	+	–	+
Palatal	+	+	–	–	–
Velar	–	–	–	+	–

observed in response to a novel stimulus or a stimulus of a different category.

In this study, we used the material of the Russian language to analyze how linguistic differences of presented word and pseudoword stimuli affect the true MMN. It has frequently been speculated that an increase in the amplitude of MMN caused by a rare deviant stimulus is due to the differences in refractivity (stimulus-specific adaptation) of neuronal populations adapted to the acoustic features of the standard and the deviant. To resolve this issue, it was proposed either to compare the responses to the deviant stimulus and to a physically identical stimulus presented among numerous equally probable sounds with the same probability as the deviant in the odd-ball paradigm, or else to compare the response to a deviant and to a physically identical stimulus presented with the same probability as the standard in the odd-ball paradigm [6–8]. These methods confirmed the existence of “identity” MMN not explained by differences in refractivity [9]. It was also shown that the optimal proportion between the probabilities of presentation of standard and deviant stimuli that minimizes the contribution of neuron refractivity to MMN corresponds to 85% standard and 15% deviant stimuli [9, 10]. In the present work, the tested acoustic stimulus was a pseudoword ***чаш*** [chash], which was presented in the multideviant odd-ball paradigm in two variants: either together with Russian words of different frequencies (experimental setting); or together with other pseudowords (control setting). That is, in the experimental variant, the pseudoword was placed into a sequence of acoustically similar Russian words of different frequencies and, hence, in a lexical context. This setting also enabled us to assess the effect of linguistic differences, such as word frequency, on the recorded auditory MMN. In the control variant, only acoustically similar pseudowords, which had no linguistic representation in the mental lexicon, were used. This excluded ERP generation in response to conceptually different stimuli, since all of them represented the same pseudoword category. To eliminate the possible influence of acoustic properties on MMN, pseudowords were constructed to resemble actual Russian words and in agreement with the language laws by substitution of a single phoneme. We paid special attention to selecting words with different frequencies, since it was important to find stimuli as similar as possible in their physical properties (duration, spectral characteristics, etc.) and to determine the frequency of their occurrence in the spoken language [11]. The study employed the passive multideviant odd-ball paradigm proposed by Näätänen [12], which enables researcher to present one standard and several deviant stimuli and thus to reduce the duration of the experiment and to specify the presentation context by increasing the number of stimuli. The main goal of the present work was to investigate the influence of the lexical context on the amplitude and latency peak of MMN induced by presentation of pseudowords.

METHODS

The study was designed to verify whether the identity MMN pattern for a given test stimulus depended on the context of its presentation. The selected pseudoword stimulus was ***чаш*** [chash], which was presented in two variants, experimental and control. In the experimental variant, the lexical context was composed of Russian words with different frequencies; the standard and the other deviant stimuli were words. In the control variant, the context was composed of pseudowords conforming to the rules of the Russian language; both the standard and the other deviant stimuli were pseudowords. The study involved 20 volunteers aged 23 to 28 years, right-handed native Russian speakers with normal hearing and without history of neurological or mental disorders; the experimental and the control setting involved 10 subjects each. The study design was approved by the Local Ethics Committee of Saint-Petersburg State University.

To minimize the acoustic differences between stimuli, they were selected in such a way that their phonetic properties were as close as possible (Table 1) [13]. The stimuli differed only in their last phoneme; the first two phonemes remained constant. It was also important to determine the lexical traits that distinguished the stimuli. For this purposes, in addition to the fundamental categorical difference between words and pseudowords, differences in lexical frequency were introduced (the frequency of word occurrence and usage in the Russian language).

In the experimental variant, the following stimuli were used: the pseudoword **[chash]** as the tested stimulus and words with different frequencies of occurrence in the Russian language. For this purpose, two words were selected: ***чан*** [chan] (English: tub, tank) with a frequency of 5.2 instances per million words (ipm) and ***час*** [chas] (English: hour) with a frequency of 643.82 ipm. The words followed the CVC formula (consonant–vowel–consonant); the word frequency

Table 2. Variants of presentation of stimuli

Stimuli and conditions	Exp	C	Exp	C	Exp	C
Standard stimulus (S)	*1*, [chan]	*1*, [chak]	*2*, [chas]	*2*, [chazh]	*3*, [chash]	*3*, [chash]
Deviant stimulus *x* (D*x*)	*2*, [chas]	*2*, [chazh]	*1*, [chan]	*1*, [chak]	*1*, [chas]	*1*, [chazh]
Deviant stimulus *y* (D*y*)	*3*, [chash]	*3*, [chash]	*3*, [chash]	*3*, [chash]	*2*, [chan]	*2*, [chak]

Exp, experimental conditions; C, control conditions.

was determined using *The New Frequency Dictionary of Russian Vocabulary* and *The Frequency Dictionary of Russian Live Speech* [11]. Each subject was presented three sets of stimuli in a pseudorandom order: (1) the low-frequency word (**[chan]**) as a standard stimulus, **[chas]** and **[chash]** as deviant stimuli; (2) the high-frequency word **[chas]** as a standard stimulus; **[chan]** and **[chash]** as deviant stimuli; (3) pseudoword **[chash]** as a standard; **[chas]** and **[chan]** as deviant stimuli (Table 2).

In the control variant including pseudowords composed similarly to words of the Russian language and in conformity with its rules, the following stimuli were used: **[chash]** as the tested stimulus, and also **[chazh]** and **[chak]**. The pseudowords **[chazh]** and **[chak]** were selected based on the phonetic features of the Russian language, which suggest that on the whole **[chak]** resembles a low-frequency word, while **[chazh]** imitates a high-frequency word (Table 1). Each subject was presented three sets of stimuli in a pseudorandom order: (1) the pseudoword **[chak]** mimicking a low-frequency word as a standard stimulus, **[chazh]**, **[chash]** as deviant stimuli; (2) the pseudoword **[chazh]** mimicking a high-frequency word as a standard stimulus, and **[chak]**, **[chash]** as deviant stimuli; (3) the pseudoword **[chash]** as a standard, and **[chazh]**, **[chak]** as deviant stimuli (Table 2).

The study design followed the passive multideviant odd-ball paradigm, according to which deviant stimuli (*Dx*, *Dy*) occur in the environment of standard stimuli (*S*). The probability of deviant occurrence among standard stimuli was set as 15% *D* among 85% *S*; as shown in [9, 10], this is the optimal proportion that minimizes the contribution of neuronal refractivity to MMN.

Stimuli were synthesized using the Acapela Group Virtual Speaker software (female voice). Their physical characteristics (amplitude, duration, intensity, spectral features) were as uniform as possible. The duration of each stimulus was 385 ms. In each setting, the presented stimuli differed only in the last phoneme. The moment where the phoneme substitution occurred was termed the divergence point. The period of time between the onset of stimulus presentation and the divergence point was 251 ms (Fig. 1).

Thus, from the onset of presentation to the divergence point, all stimuli were identical. The post-stimulus pause was 500 ms with randomization of up to 50 ms. In each setting, subjects were presented altogether 1334 stimuli in a pseudorandomized order.

After the experiments, subjects were interviewed to evaluate the perception of words and pseudowords, as well as potential distortions and associations.

The total duration of the experimental session was 90 min. During this time, a subject was presented three control or three experimental sets of stimuli of approximately 25 min each. Subjects were instructed to remain as calm and relaxed as possible and to watch a soundless video on the screen in front of them; they did not need to pay attention to the stimuli presented.

EEG recording. During experiments, subjects occupied an acoustically isolated room. Stimuli were presented binaurally via headphones at a comfortable volume (50 dB) using the Presentation program (Neurobehavioral Systems, Inc, 2015, www.neurobs.com). Since the aim of the study was MMN analysis, and this ERP component is mainly generated in the frontal auditory cortex, it was recorded using those leads where MMN is most pronounced: Cz, C_3, C_4, Fz, F_3, and F_4. EEG was recorded using Ag/AgCl electrodes positioned on the surface of the head according to the International 10–20 System. The reference electrode was located on the nose tip, and the ground electrode was on the forehead. Electrical artifacts caused by eye movements were controlled by electrooculography (EOG). The electrode resistance was below 5 kΩ. The signal was recorded digitally with a frequency of 250 Hz and filtered in the 1–30 Hz band. The isoline was corrected based on the 100-ms period preceding the stimulus. Epochs where EEG and/or EOG signals exceeded 100 μV were considered as artifacts and excluded from the analysis. ERP data where the portion of artifactual deviant or standard stimuli exceeded 15% were also excluded from the subsequent group mean calculation and statistical analysis.

EEG was recorded using a Mitsar 24-channel digital electroencephalograph (bandwidth, 0.05–70 Hz) and the WinEEG software package for EEG processing (Ponomarev, Bechtereva Institute of the Human Brain, Mitsar Inc., Russia, Saint-Petersburg).

Thus, the proposed experimental design enabled us to determine identity MMN, since the acoustic contrast between the standard and the deviant stimuli was identical in all three combinations. Identity MMN was calculated as the difference of ERPs caused by the same stimulus presented as a standard and as a deviant

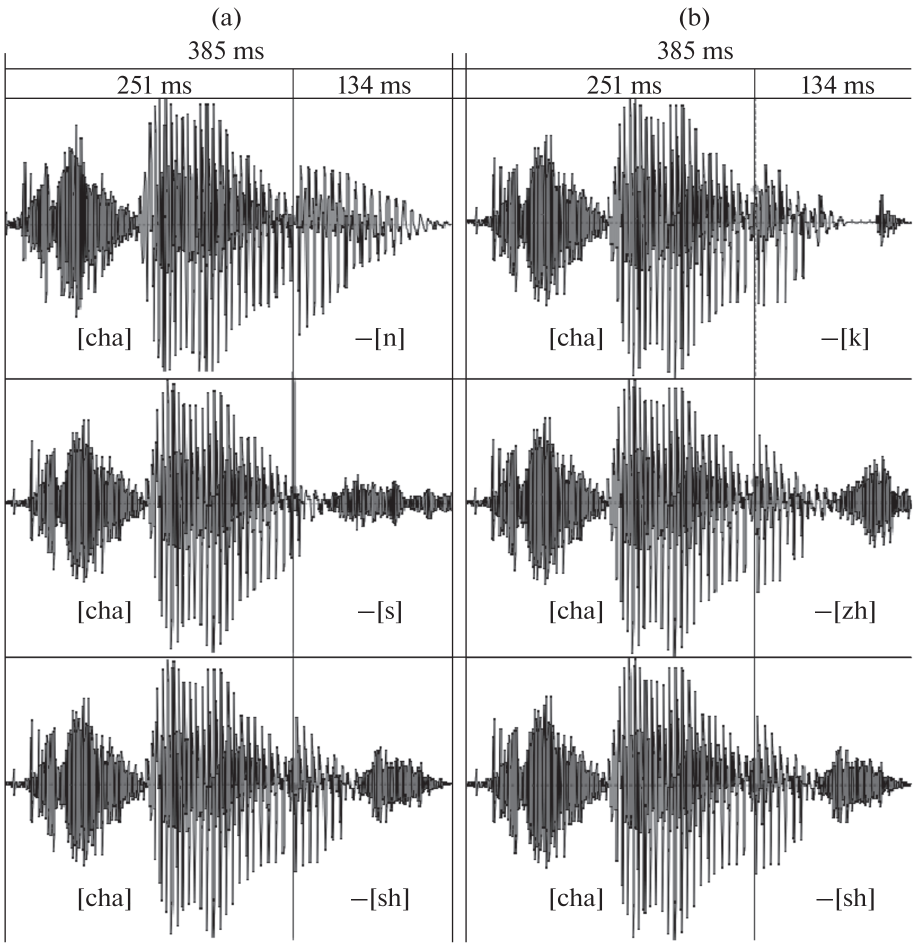

Fig. 1. Oscillograms of the stimuli used (a) in the lexical context and (b) in the pseudowords context. X axis, duration of stimuli, ms. The total duration of each signal was 385 ms; the first part of a signal (two first phonemes) was 251 ms long; vertical line shows the point of divergence; the last phoneme (different between stimuli) was 134 ms long.

[6, 7, 14]. The peak latency of MMN was calculated for each subject under each condition. MMN was determined as a negative wave in the interval of 100–200 ms. Statistical analysis of MMN was performed in the 88–188 ms interval for the experimental setting and in the 128–224 ms interval for the control setting. To obtain a statistical estimate of physical variation of stimuli, we compared all words presented as a standard from the onset of presentation to the divergence point. Statistical analysis of the data was performed using analysis of variance (ANOVA; IBM SPSS Statistic (v. 18, IBM Corporation, New York, USA), and the Bonferroni correction was used when necessary. A three-factor model with the factors Stimulus Type (three levels: one tested and two context stimuli), Condition (two levels: standard and deviant), and Lead (six levels: F_3, Fz, F_4, C_3, Cz, and C_4) was used.

RESULTS

Experimental Setting with a Lexical Context

ERPs caused by the stimuli presented as standards did not exhibit significant differences from the onset to the divergence point and in the 88–188 ms interval ($p > 0.05$; Fig. 2a).

Repeated-measures ANOVA for ERPs caused by deviant stimuli showed that the amplitude and latency of responses in the 88–188 ms interval were significantly affected by the factors Stimulus Type ($F_2 = 10.741$, $p = 0.001$) and Condition ($F_2 = 5.886$; $p = 0.014$), as well as by the interaction Stimulus Type × Condition ($F_{2,\ 801} = 9.429$; $p = 0.001$). Pairwise comparisons showed that the amplitude and the latency of ERP caused by deviant low-frequency word **[chan]** were significantly different from those caused by the deviant high-frequency word **[chas]** ($p = 0.008$). There were no significant differences between ERPs

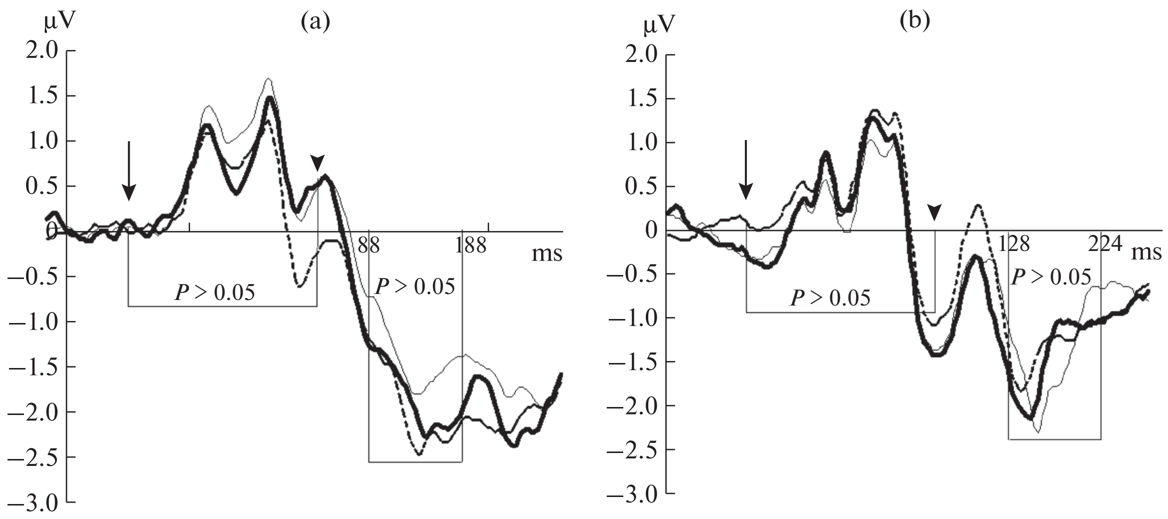

Fig. 2. ERPs caused by stimuli presented as standards.
Summarized data from frontal leads ($n = 10$). X axis, ERP latency, ms; Y axis, ERP amplitude, μV. The first arrow indicates the beginning of presentation, the second arrow shows the divergence point. (a) Experimental variant: thin line, low-frequency word; bold line, high-frequency word; dashed line, tested pseudoword **[chash]**; (b) control variant: thin line, pseudoword **[chak]**; bold line, pseudoword **[chazh]**; dashed line, tested pseudoword **[chash]**.

caused by deviant signals **[chash]** and **[chan]** ($p = 0.8$), as well as by **[chash]** and **[chas]** ($p = 0.2$).

For the identity MMN (calculated as the difference between the responses to the same signal presented as a deviant and as a standard), significant effects on the amplitude and the latency in the 88–188 ms interval were observed for the factors Stimulus Type (F_2 = 4.320; $p < 0.032$) and Condition (F_2 = 3.885, $p < 0.039$), as well as for the interaction Stimulus Type × Condition ($F_{10} = 3.584$; $p < 0.001$). Pairwise comparisons showed that the amplitude and latency of identity MMN for the pseudoword **[chash]** were significantly different from those caused by the high-frequency word **[chas]** ($p = 0.036$), while the amplitude and latency of identity MMN for the high-frequency word **[chas]** were significantly different from those for the low-frequency word **[chan]** ($p = 0.037$). There were no significant differences between the amplitudes and latencies of identity MMN caused by the pseudoword **[chash]** and the low-frequency word **[chan]** ($p = 0.709$; Fig. 3a).

Control Setting with Pseudowords

ERPs caused by all three pseudowords presented as standards did not exhibit significant differences from the onset to the divergence point and in the 128–224 ms interval ($p > 0.05$; Fig. 2b).

Repeated measures ANOVA for ERP caused by deviant stimuli showed that the factor Conditions had a significant effect on the response amplitude and latency in the 128–224 ms range: $F_{1,\,074} = 33.750$; p = 0.001. No significant interaction between factors was detected.

Repeated measures ANOVA did not detect significant differences between the identity MMN caused by the stimuli ($p > 0.05$; Fig. 3b).

Significant differences were observed in the 88–216 ms interval between ERPs of the same pseudoword **[chash]** presented as a deviant stimulus within a lexical context and in a pseudoword context ($F_{1,\,000} = 5.587$; $p = 0.026$; Fig. 4a). Moreover, the identity MMNs of the pseudoword **[chash]** obtained under conditions of a lexical context and a pseudoword context were significantly different in the 88–216 ms interval: $F_{1,\,000} = 8.924$; $p = 0.006$ (Fig. 4b).

Comparison of identity MMN curves for all stimuli used in the study revealed that peak latencies for pseudowords were sometimes nearly twice as long as peaks latencies of responses to words. For instance, for the pseudoword **[chash]** presented in a lexical context, the peak latency was recorded at 112 ms, which was significantly different from the peak latency recorded at 200 ms when the same pseudoword was presented with other pseudowords ($p = 0.006$). The amplitude of responses also differed considerably between the two settings; in some cases, MMN amplitudes caused by stimuli in a lexical context were more than twice as high as in a pseudoword context. We found that the MMN amplitude for the pseudoword **[chash]** presented in a lexical context was 1.95 μV, whereas the amplitude caused by the same pseudoword in the control setting with other pseudowords was only 0.46 μV. In the experimental setting, there was also a significant

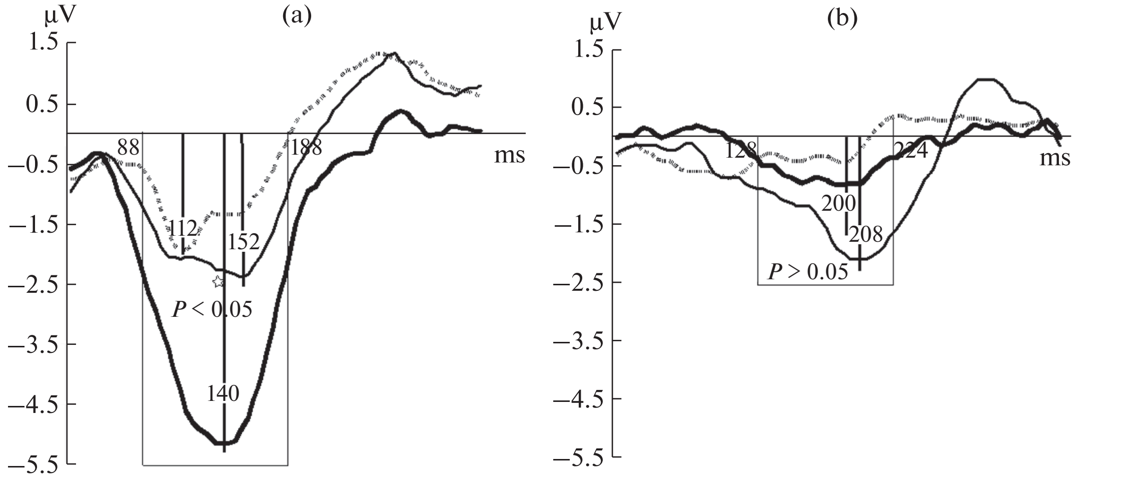

Fig. 3. Identity MMN in different variants of presentation.
Summarized data from frontal leads ($n = 10$) are shown starting from the divergence point. X axis, ERP latency, ms; Y axis, ERP amplitude, μV. The maximal amplitude peak of identity MMN is marked, and its latency is indicated in ms. (a) MMN in the experimental variant with a lexical context: thin line, MMN for the low-frequency word; bold line, MMN for the high-frequency word; dashed line, MMN for the tested pseudoword **[chash]**; (b) MMN caused in the control variant with a pseudoword context: thin line, MMN for the pseudoword **[chak]**; bold line, MMN for the pseudoword **[chazh]**; dashed line, MMN for the tested pseudoword **[chash]**.

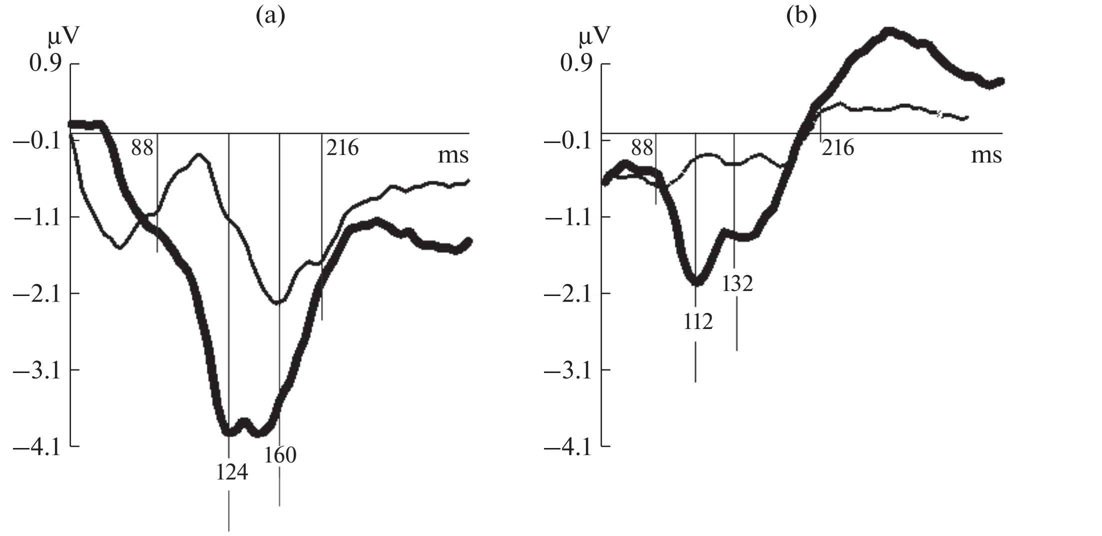

Fig. 4. ERP to the test pseudoword **[chash]** presented in different variants. Summarized data from frontal leads ($n = 10$) are shown starting from the divergence point. X axis, ERP latency, ms; Y axis, ERP amplitude, μV. The maximal amplitude peak of ERP is marked, and its latency is indicated in ms. (a) ERP caused by the tested pseudoword **[chash]** as a deviant stimulus: thin line, ERP in the control variant with a pseudoword context; bold line, ERP in the experimental variant with a lexical context. (b) Identity MMN caused by the tested pseudoword **[chash]**: thin line, MMN in the control variant with a pseudoword context; bold line, MMN in the experimental variant with a lexical context.

difference between the amplitudes of responses to the high-frequency word **[chas]** and the low-frequency word **[chan]** (5.16 μV vs. 2.39 μV; $p = 0.037$).

Both in the experimental and in the control setting, the interactions Stimulus Type × Lead and Conditions × Lead were not significant. There were no significant differences between symmetrical leads.

DISCUSSION

The goal of this work was to investigate how lexical context affects the amplitude and the peak latency of MMN evoked by presentation of pseudowords. Identity MMN was determined as the difference between the responses to the same stimulus (a word or a pseudoword) presented as a standard and as a deviant in the multideviant odd-ball paradigm. The stimuli used were Russian words **[chas]** (a high-frequency word) and **[chan]** (a low-frequency word), as well as pseudowords acoustically similar to these words: **[chazh]**, **[chak]**, and **[chash]** (the tested one). Stimuli were acoustically similar to minimize the influence of their physical characteristics on the neurophysiological response. The acoustic contrast between the standard and the deviant was identical in all three combinations. The physical parameters of the stimuli (amplitude, duration, intensity, spectral characteristics) were as close as possible. In this work, the effect of the acoustic properties on ERPs was negligible, as shown by the lack of significant differences between ERPs evoked by standard stimuli ($p > 0.05$).

In the control setting with pseudowords, identity MMN to different stimuli did not exhibit significant differences, presumably because the pseudowords were selected in such a way as to minimize the acoustic contrast. On the other hand, pseudowords are not represented in the mental lexicon, and therefore cannot be distinguished on the lexical level. Noteworthy, previous research showed that repeated presentation of initially unknown words led to a change in the MMN pattern: the amplitude of the response increased, and the latency period diminished [4, 15, 16]. The authors presumed that this effect reflected neuronal plasticity associated with the integration of the new words into the mental lexicon. Thus, the observed lack of difference between MMN caused by pseudoword stimuli results only from insignificance of difference between their acoustic traits.

In the experimental setting, no significant difference was observed between the amplitude and the latency of identity MMN for the pseudoword **[chash]** and for the low-frequency word **[chan]** ($p = 0.709$), although the word-induced MMN was slightly more pronounced. The word **[chan]** occurs rarely in the spoken language and has a lemma frequency of only 5.2 ipm (instance per million words) [11]. Apparently, the linguistic contrast between a low-frequency word and a pseudoword that does not exist in the lexicon was minimal and insufficient for significant difference to be observed under the conditions of our experiment. At the same time, the MMN caused by the high-frequency word **[chas]** had a significantly higher amplitude than the MMN for the tested pseudoword **[chash]** (5.16 vs. 1.95 μV; $p = 0.036$).

Our results demonstrate that there was a significant difference between MMN responses caused by one and the same pseudoword presented in different contexts ($p = 0.006$): in the control setting with a pseudoword context, the identity MMN had a higher latency and a lower amplitude. In the experimental setting with a real word context, the same tested stimulus generated an MMN response with a shorter latency and a higher amplitude. It was shown that, in the odd-ball paradigm, the use of deviant stimuli basically different from standard ones causes a strong increase in MMN, which is known as the reaction to a novel stimulus [17]. Apparently, a pseudoword presented among real words in our experimental setting was perceived as a stimulus of a fundamentally different kind, and probably the perception of the pronounced contrast between stimuli (word vs. pseudoword) caused a reaction similar to the reaction induced by novel stimuli, i.e., a significant enhancement of MMN. It is the fact that the tested pseudoword **[chash]** represented a different category of stimuli, i.e., a novel stimulus, that explains the observed increase in the MMN it evoked in the experimental setting, in contrast to the control setting where it did not differ basically from the context, as one nonexistent pseudoword among others, and accordingly generated a relatively weak MMN [18].

MMN latencies for pseudowords were significantly longer than for words; however, when a pseudoword was tested, the latency of identity MMN could be determined only tentatively, because the amplitude of the MMN wave was low, and the local low-amplitude peaks were barely distinguishable. Our results suggest that, if only pseudowords are presented, the reaction is delayed, because they are not recognized as known words but are processed as unknown stimuli [19]. On the other hand, if a pseudoword is presented in a linguistic context with words, it causes an MMN response by mechanisms typical for novel stimuli.

It should be admitted that the use of pseudowords as control units in the analysis of effects of purely acoustic differences on word perception must be exercised with caution. Taking into account the results concerning pseudoword perception, we believe that it would be more correct to present them in the paradigm where no words are used. In addition, the results may be affected by other factors, such as potential similarity between the pseudoword and some real word, or the categorical contrast.

In the experimental setting it was also found that the amplitude of the identity MMN of the high-frequency word in the 88–188 ms interval was significantly higher than the MMN amplitude for the low-frequency word, which additionally confirms that a higher word usage is associated with an increase in the MMN amplitude [2, 20]. It should be noted that the previous studies employed only two words of different frequencies; in the present work, we also used pseudowords and showed that the observed significant differences between the identity MMN patterns ($p = 0.037$) were indeed determined by different word frequencies; that is, words of higher frequencies cause identity MMN of higher amplitudes. The latency of the identity MMN for the high-frequency word was much lower that for the low-frequency word. The differences in the parameters of identity MMN for words cannot be explained only by their acoustic contrast, since it was minimal, and most probably reflect the effects of lexical frequency involving activation of long-term memory traces. It can be supposed that the processing of speech and language involves a broad network of neuronal ensembles, and instantaneous activation of this network leads to a rapid nearly simultaneous activity of all its connections, which is observed as MMN [21, 22]. Thus, the magnitude of the brain response must depend on neuronal representations developing in the long-term memory.

CONCLUSIONS

On the whole, our data support the hypothesis that the context of presentation affects the characteristics of identity MMN. We found that one and the same pseudoword presented in different contexts induced different MMN responses. In particular, MMN generated in response to a pseudoword presented in a context of other pseudowords had comparatively low amplitudes and long latencies. Presentation of the same pseudoword in a context of real words resulted in a significant increase in the response amplitude and in diminished peak MMN latency in the 100–200 ms interval. We suppose that, in the experimental setting, a pseudoword presented among words was perceived as a stimulus of a fundamentally different category, which enhanced MMN by the mechanism of reaction to a novel stimulus.

The described differences between the identity MMN patterns observed at the pseudoword presentation in a pseudoword only context and in a context with words apparently reflect the tendency to delayed and less precise recognition of unknown stimuli. Presumably, the processing of stimuli in a pseudoword context takes longer time because they have no representation in the mental lexicon and therefore are more difficult to identify.

Our results also confirm the hypothesis about the effect of word frequency on MMN parameters. A high-frequency word caused an MMN response with a significantly higher amplitude and shorter peak latency than a low-frequency word. Apparently, the frequent use of words enhances neuronal connections involved in their processing and accordingly modifies their representations in the long-term memory.

ACKNOWLEDGMENTS

This study was supported by the Russian Foundation for the Humanities, project no. 15-06-10806.

REFERENCES

1. Näätänen, R., Lehtokoski, A., Lennes, M., et al., Language-specific phoneme representations revealed by electric and magnetic brain responses, *Nature*, 1997, vol. 385, p. 432.
2. Alexandrov, A.A., Boricheva, D.O., Pulvermüller, F., and Shtyrov, Yu., Strength of word-specific neural memory traces assessed electrophysiologically, *PLoS One*, 2011, vol. 6, no. 8, p. e22999. doi 10.1371/journal.pone.0022999
3. Tamminena, H., Peltolaa, M.S., Kujalad, T., and Näätänen, R., Phonetic training and non-native speech perception – new memory traces evolve in just three days as indexed by the mismatch negativity (MMN) and behavioural measures, *Int. J. Psychophysiol.*, 2015, vol. 97, no. 1, p. 23.
4. Davis, M.H. and Gaskell, M.G., A complementary systems account of word learning: Neural and behavioural evidence, *Philos. Trans. R. Soc., B*, 2009, vol. 364, no. 1536, p. 3773.
5. Aleksandrov, A.A., Memetova, K.S., Stankevich, L.N., and Uplisova, K.O., The effect of the word frequency in Russian Language on mismatch negativity (MMN) in the event related potentials (ERP), *Ross. Fiziol. Zh. im. I.M. Sechenova*, 2016, vol. 102, no. 6, p. 717.
6. Näätänen, R., Pakarinen, S., Rinne, T., and Takegata, R., The mismatch negativity (MMN): Towards the optimal paradigm, *Clin. Neurophysiol.*, 2004, vol. 115, no. 1, p. 140.
7. Pakarinen, S., Takegata, R., Rinne, T., et al., Measurement of extensive auditory discrimination profiles using the mismatch negativity (MMN) of the auditory event-related potential (ERP), *Clin. Neurophysiol.*, 2007, vol. 118, no. 1, p. 177.
8. Shtyrov, Y., Kujala, T., and Pulvermüller, F., Interactions between language and attention systems: Early automatic lexical processing?, *J. Cognit. Neurosci.*, 2010, vol. 22, no. 7, p. 1465.
9. Evstigneeva, M.D. and Aleksandrov, A.A., Mismatch negativity: contribution of difference in refractoriness of stimulus-specific neuronal populations, *Ross. Fiziol. Zh. im. I. M. Sechenova*, 2008, vol. 94, no. 10, p. 1147.
10. Evstigneeva, M.D. and Aleksandrov, A.A., Mismatch negativity: The contribution of differences in the refractoriness of stimulus-specific neuron populations, *Neurosci. Behav. Physiol.*, 2009, vol. 39, no. 9, p. 833.
11. Lyashevskaya, O.N. and Sharov, S.A., *Chastotnyi slovar' sovremennogo russkogo yazyka (na materialakh Natsional'nogo korpusa russkogo yazyka) (Frequency Dictionary of Modern Russian Based on the Materials of the National Body of the Russian Language)*, Moscow: Azbukovnik, 2009.
12. Näätänen, R. and Alho, K., Mismatch negativity – the measure for central sound representation accuracy, *Audiol. Neurootol.*, 1997, vol. 2, no. 5, p. 341.
13. Musatov, V., *Russkii yazyk. Fonetika. Fonologiya. Orfoepiya. Grafika. Orfografiya (Russian Language. Phonetics. Phonology. Orthoepy. Graphics. Orthography)*, Moscow: Flinta, 2012.
14. Shtyrov, Y. and Pulvermuller, F., Neurophysiological evidence of memory traces for words in the human brain, *NeuroReport*, 2002, vol. 13, no. 4, p. 521.
15. Shtyrov, Y., Neural bases of rapid word learning, *Neuroscientist*, 2012, vol. 18, no. 4, p. 312.
16. Hawkins, E., Astle, D.E., and Rastle, K., Semantic advantage for learning new phonological form representations, *J. Cognit. Neurosci.*, 2015, vol. 27, no. 4, p. 775.

17. Tiitinen, H., May, P., Reinikainen, K., and Näätänen, R., Attentive novelty detection in humans is governed by pre-attentive sensory memory, *Nature*, 1994, vol. 372, p. 90.

18. Shestopalova, L.B., Petropavlovskaia, E.A., Vaitulevich, S.Ph., and Nikitin, N.I., Contextual effects on preattentive processing of sound motion as revealed by spatial MMN, *Int. J. Psychophysiol.*, 2015, vol. 96, no. 1, p. 49.

19. Shtyrov, Y. and Lenzen, M., First-pass neocortical processing of spoken language takes only 30 msec: Electrophysiological evidence, *Cognit. Neurosci.*, 2017, vol. 8, no. 1, p. 24. doi 10.1080/17588928.2016.1156663

20. Strotseva-Feinschmidt, A., Cunitz, K., Friederici, A.D., and Gunter, T.C., Auditory discrimination between function words in children and adults: A mismatch negativity study, *Front. Psychol.*, 2015, vol. 6, p. 1930.

21. Scharinger, M., Bendixen, A., Trujillo-Barreto, N.J., and Obleser, J., A sparse neural code for some speech sounds but not for others, *PLoS One*, 2012, vol. 7, no. 7, doi 10.1371/journal.pone.0040953

22. Scharinger, M., Monahan, Ph.J., and Idsardi, W.J., Linguistic category structure influences early auditory processing: Converging evidence from mismatch responses and cortical oscillations, *NeuroImage*, 2016, vol. 128, p. 293.

Translated by D. Timchenko

SPELL: 1. OK