Psychology. Journal of the Higher School of Economics.
2015. Vol. 12. N 4. P. 64–80.

CORTICAL RESPONSES OF 7–10-YEAR-OLD CHILDREN TO EASY AND DIFFICULT CONTRASTS IN DISCRIMINATION OF PSEUDOWORDS

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This work was supported by the Center for International Mobility (CIMO) and the Jenny and Antti Wihuri Foundation, the Academy of Finland (grant 79406), and the European Science Foundation. This study was supported by RFBR according to the research project № 14-06-00349a and within the framework of a subsidy granted to the National Research University Higher School of Economics by the Government of the Russian Federation for the implementation of the Global Competitiveness Program.

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Abstract

Exposure-based development of brain responses of 7–10-year-old Finnish children to two speech contrasts incorporated in pseudowords (PWs) and varying in perceptual difficulty were studied. An oddball paradigm was used to record event-related potentials (ERPs) to a frequently presented standard PW /baka/ and two infrequent deviant PWs: the easier = /baga/ and the more difficult /bag*a/ that sounded as intermediate between /baka/ and /baga/. The ability of children to actively discriminate the more difficult contrast was investigated in two separate behavioral sessions that alternated with the ERP recording blocks. The enhanced amplitude of the most negative response to the standard, not to the deviants, suggested formation of an auditory template for the frequent PW during the experiment. There was no reliable block effect on the amplitude of the mismatch negativity (MMN), an automatic index of an experience-dependent auditory memory trace. This suggests consolidation of the short-term representation of the repetitively presented PW during passive exposure to stimuli, rather than changes in the preattentive discrimination process. This was also supported by the evidence from a behavioral discrimination test. No perceptual learning to discriminate the difficult speech contrast could be detected in the children in absence of the active behavioral discrimination.

Keywords: auditory ERPs, children, mismatch negativity, MMN, pseudoword, perceptual experience.

Introduction

The majority of event-related potential (ERP) studies on language have focused on processing of isolated sounds, be it tones, vowels, or consonant-vowel (CV) syllables. Everyday language comprehension, however, involves encoding and perceiving speech sounds incorporated in strings of other sounds, often long and quickly spoken. Therefore, the mechanisms behind the perception of consonants, (the most difficult sounds to identify in speech), need to be studied in a context similar to that of spoken language. Since processing words of one's native language is affected by long-term perceptual, phonological, and semantic knowledge obtained during language acquisition, the use of pseudowords (PWs) can serve this purpose better.

Using PWs along with real words in an auditory sensory discrimination study allows one to relate the ability to preattentively discriminate auditory stimuli to higher stages of speech processing and language learning (Diesch, Biermann, & Luce, 1998; Pulvermüller et al., 2001; Jacobsen et al., 2004; Aerts, van Mierlo, Hartsuiker, Santens, & De Letter, 2015). To the best of our knowledge, only a few ERP studies have been conducted upon perception of PWs as such, aimed at studying the prelexical level of speech processing and reflecting pure phonological analysis (Connolly, Service, D'Arcy, Kujala, & Alho, 2001; Čeponienė, Service, Kurjenluoma, Cheour, & Näätänen, 1999; Kast, Elmer, Jancke, & Meyer, 2010; Coch & Mitra, 2010). The short-term maintenance and learning of new words (such as PWs) is largely a function of the phonological loop, or a phonological short-term memory (PSTM) (Baddeley, 1997).

PSTM is strongly implicated in new word acquisition during early childhood and foreign language learning during school years (Gathercole & Baddeley, 1989; Baddeley, Gathercole, & Papagno, 1998; Gathercole, 2006). Čeponienė et al. (1999) showed in Finnish 7–9-year-old children that differences in PSTM, as tapped by a pseudoword repetition test, were paralleled by differences in the accuracy of auditory sensory discrimination, as reflected by an ERP component, the mismatch negativity (MMN) that was elicited by a difficult PW contrast.

The MMN component of the long-latency auditory ERPs is well suited for examination of speech perception and learning in children (for reviews, see Cheour, Korpilahti, Martynova, & Lang, 2001; Kraus & Cheour, 2000; Leonard, 2014), because it does not require active attending to the stimuli. The MMN has been thought to index echoic memory (Näätänen & Winkler, 1999). It is typically elicited by "deviant" stimuli, infrequently and randomly presented among frequent "standard" sounds in so-called oddball paradigms. Depending on the stimuli, the MMN characteristics can be adult-like at already 5–8 years of age (Čeponienė, Cheour, & Näätänen, 1998; Csépe, 1995; Kraus, McGee, Sharma, Carrell, & Nicol, 1992; Kraus, McGee, Micco, Sharma, & Nicol, 1993; Kraus, Koch, McGee, Nicol, & Cunningham, 1999; Archibald, Joanisse, & Shepherd, 2008; Medina, Hoonhorst, Bogliotti, & Serniclaes, 2010). The MMN can be modulated by learning in adults (Kraus et al., 1995; Tremblay, Kraus, Carrell, & McGee, 1997; Tremblay, Kraus, & McGee, 1998; Winkler et al., 1999; Atienza, Cantero, & Quiroga, 2005), children (Bradlow et al., 1999), and infants (Cheour et al., 1998). In children, a reliable MMN has been reported to small acoustical contrasts incorporated in just discriminable consonant-vowel syllables (Kraus et al., 1993, 1999).

In the present experiment, we manipulated the degree of perceptual discriminability between two PWs. With an easy-to-discriminate contrast we aimed at providing reliable indices of the discrimination of two consonants embedded within PWs. Another difficult-to-discriminate contrast in turn allowed the study of the time course in perceptual learning. The experiments were conducted both behaviorally and by recording the ERPs. Two behavioral discrimination sessions involving experience of the difficult-to-discriminate contrast were interleaved between the three ERP recording blocks.

Korpilahti et al. (2001) has suggested that in children auditory processing of a PW activates brain processes involved in the formation of a memory trace for that particular new word rather than just processes related to the acoustic-level comparison of this novel input with an existing sensory memory trace, i.e. MMN. Such a build-up of central sound representation would most probably be reflected in the ERP to the repeating standard-stimulus.

To test the hypothesis of parallel, and perhaps competing, events of trace formation for a PW and the discrimination of phonemes contained in that non-word, we monitored the dynamics of the responses to frequent and infrequent PWs in the course of the experiment that comprised three blocks of auditory stimuli. If the MMN changed as a result of perceptual experience, then the corresponding changes in behavioral performance in an active discrimination task would be likely to be observed. To test for this, we introduced two blocks of active behavioral discrimination of the difficult PW contrast.

Methods

Subjects

Twenty-eight healthy Finnish school-age children (10 males) participated in the study. Their mean age was 8 yrs 10 mths (range 7 yrs 5 mths – 10 yrs 1 mth). The ERP data recorded from seven children were rejected from further analysis because of artifacts. None of the children were reported to have any hearing or academic achievement problems at school. They volunteered with their parents' written consent. The study was approved by the Ethical Committee of the Department of Psychology, University of Helsinki. The subjects' phonological short-term memory was tested using a Finnish PW repetition and PW span task (cf. Čeponienė, et al., 1999; Gathercole, Willis, Baddeley, & Emslie, 1994). All subjects were relatively good repeaters as compared to a group tested in an earlier study (Čeponienė, et al., 1999).

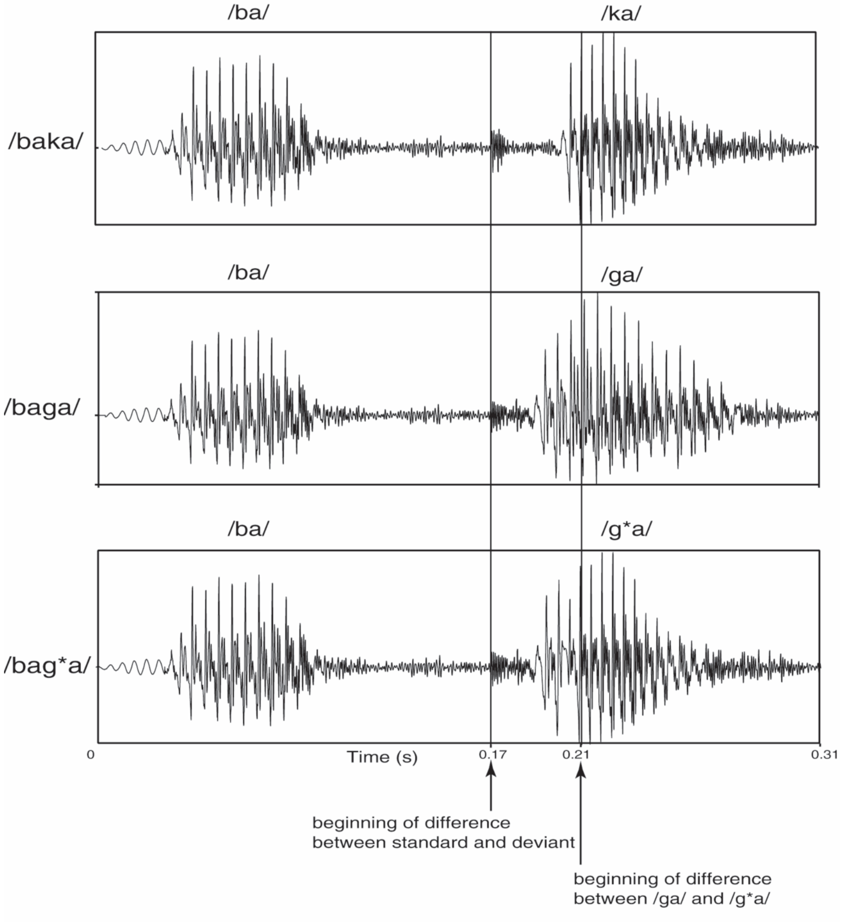
Stimuli

An oddball stimulus paradigm was used to record ERPs to a standard PW /baka/ and two deviant PWs /baga/ and /bag*a/. The /g/ and /*g/ are not consonants in the core phoneme inventory of the Finnish language. In the present experiment, we further manipulated the non-Finnish language /g/–/k/ contrast. A PW /bag*a/ was constructed that sounded in-between /baka/ and /baga/, and thus comprised a difficult speech contrast (Figure 1). Therefore, the /bag*a/ deviant is hereafter referred to as difficult as opposed to the relatively easy-to-discriminate /baga/ deviant, which is hereafter referred to as easy.

The standard and deviant stimuli were 310 ms in duration including 10-ms rise and fall times (Figure 1). The stimuli differed in only the second syllable. Originally, two stimuli, /baka/ and /baga/, were pronounced by a Finnish female speaker and digitized by Signalyze software at a sampling rate of 22 kHz. The /baka/ PW served as a standard. The easy deviant was constructed from /baka/ by replacing the second syllable, starting from the latency of 169 ms, namely from the beginning of the noise burst, by the corresponding section cut from the original /baga/. The splice started with a noise burst and made up the syllable /ga/. The resulting easy stimulus hence sounded like /baga/ and contained the same first syllable as the standard. The difficult deviant was constructed from /baka/ by splicing in only a 41-ms segment from

Figure 1

Acoustical waveforms of the standard /baka/ (top) and the two deviant, /baga/ (middle) and /bag*a/ (bottom), PWs



Note. The first, /ba/, syllable was identical in the standard and deviant PWs. The PWs differed in the second syllable, starting at the latency of 169 ms, and the two deviants differed from 210 ms onwards.

the second syllable in /baga/ rather than the whole syllable. This again resulted in an insert at 169 ms where the noise burst started. As a result, the difficult stimulus sounded like something in between the standard /baka/ and the easy deviant /baga/. The difference between the standard and deviant PWs hence started at 169 ms after stimulus onset, and the two deviants differed from 210 ms onwards. For the standard /baka/ stimulus, the voice onset time (VOT) from the end of the noise burst to the beginning of the voicing in the second syllable was 22 ms whereas the deviant stimuli had VOTs of 0 ms. However, the VOT generally cannot be considered the only difference between voiced and unvoiced stop consonants in Finnish.

Electroencephalogram (EEG) recording and response averaging

The standard and deviant sounds were presented in 3 blocks of 1000 events each; with the interstimulus interval (ISI, offset-to-onset) being 500 ms. Both deviants were randomly interspersed among the standards with a probability of 8% each.

Stimuli were delivered by the NeuroStim software and presented via two loudspeakers placed behind the subject. The sound pressure level was equal to 55 dB at the subject's head.

The experiments were conducted in an acoustically and electromagnetically shielded chamber. During the experiment subjects sat in a comfortable armchair in front of a TV screen at a distance of 1.8 m watching silent cartoons of their choice. Throughout the experiment they were video-monitored. The sessions lasted 1.5 hours on average.

The EEG (amplified by SynAmps at DC–30 Hz and digitized at 250 Hz) was recorded using a NeuroScan PC–3.0 based system. Silver/silver chloride electrodes were attached to the F3–4 (frontal left–right) and C3–4 (central left–right) scalp sites, according to the International 10–20 system. During the recordings, scalp electrodes were referred to the right mastoid. The ground electrode was placed on the forehead. In order to avoid a hemispheric bias, the data were re-referenced offline to the average of right and left mastoid recordings. Eye movements were monitored with two electrodes, one below and the other at the outer canthus of the right eye. The EEG was digitally filtered (bandpass 1–15 Hz, 24 dB/ octave roll-off) and averaged off-line. The raw data were first epoched into 800-ms intervals. These included 100ms of pre-stimulus time, which was used for a baseline correction. Epochs following each deviant, the first 3 epochs of each block, as well as the trials with the EEG or EOG voltage exceeding ±100 μV in any channel were omitted from averaging. In each block, the remaining epochs of each subject were averaged separately for the standards and for both deviants (69 and 67 events were accepted on the average, respectively). Subjects with less than 65 accepted deviant trials in each block were excluded from further analysis.

Behavioral Discrimination Task

The subjects performed behavioral discrimination tasks during two separate sessions alternating with the ERP recordings. During the behavioral task, the video presentation was switched off. In order to improve the quality of perception and avoid unnecessary distraction, the stimuli were delivered using headphones. Each behavioral session lasted about 10 minutes.

The 210 stimuli (including standard and difficult deviant in order to provide experience of the difficult speech contrast in the active discrimination sequence) were grouped into trains of four, separated by 3-s inter-train intervals. Within a train, the ISI was 500 ms. Each train began with 3 standard stimuli, and the fourth was either the standard or the difficult deviant: /baka baka baka baka/ or /baka baka baka bag*a/. The subject was instructed to push the button on a response pad when the fourth stimulus was different from the standards and not to press it when it was the same. An equal number of trains, ending with either a standard or a deviant stimulus, appeared in a random order. Before the main experiment, the subject was familiarized with the behavioral task: 4-stimulus trains ending in the easy deviant were presented in a single behavioral session until the subjects' conclusive correct responses were obtained.

ERP data analysis

ERPs to the standard stimulus

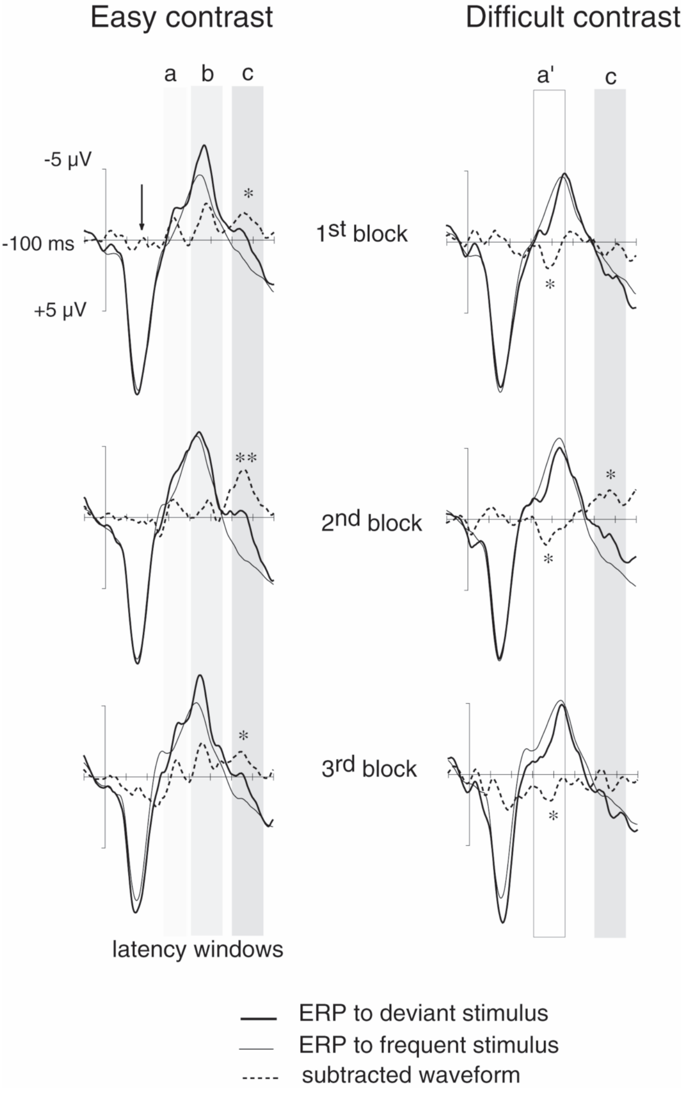
The time intervals for automatic measurements of the ERP peak latencies were selected on the basis of visual inspection of the grand-average waveforms. The most prominent negative response to the standards peaked at a latency of about 430 ms (Figure 2). Based on its latency, we call this obligatory negativity the N430 here, although being the first and major negativity, it most likely corresponds to the N250 elicited by tones in children (Čeponienė, et al., 1998; Ponton, Eggermont, Kwong, & Don, 2000; Sussman, Steinschneider, Gumenyuk, Grushko, & Lawson, 2008). The mean amplitudes of the standard stimulus response at each electrode were measured, in reference to the 100 ms baseline, with a 20-ms integration window centered at group-average peak latencies of C3 and C4 leads (for both hemispheres, respectively). The statistical presence of the standard response across the blocks was verified by comparing their amplitudes to 0 mV, using two-tailed t-test analyses. Statistical comparisons of mean amplitudes and peak latencies were made using analysis of variance (ANOVA) with the following factors: Block (1st, 2nd, and 3rd), Laterality (left and right hemisphere electrodes), and Frontality (frontal and central electrodes). A least-significant difference (LSD) post hoc test was used to find the sources of the significant main ANOVA effects and interactions. Greenhouse-Geisser correction was used for factors with more than two levels (corrected p-values are reported).

Difference responses

The MMN response was defined as the most prominent negativity in the difference waveform (ERP to the standard stimulus subtracted from the ERP to the deviant stimulus). For the easy contrast, three distinguishable negative displacements were found in the difference curves (Figure 2). Therefore, the magnitude of the MMN response to this contrast was estimated in three latency windows (according to Schulte-Körne, Deimel, Bartling, & Remschmidt, 2001): 275–400 ms (window 'a'), 400–550 (window 'b'), and 600–750 ms (window 'c') (Figure 2). For the difficult contrast, the negative displacement was seen in the grand-average waveform only in the 'c' window preceded by a positive deflection in the windows 'a' and 'b'. The MMN amplitudes at each electrode and each subject were calculated separately for each of the three latency windows: mean amplitudes were measured using a 20-ms integration window centered around the left and right central electrodes at latencies of most negative peaks in the grand-averaged waveforms

Figure 2

Grand-average ERP waveforms recorded at the C3 electrode during the first, second, and third ERP blocks



Note. The three latency windows for magnitude estimation of the MMN are marked as ‘a’, ‘b’, and ‘c’ boxes, correspondingly, and shaded in gray. The transparent box (a’) indicates the latency window used for measuring the positive deflection in the difference waveform. The arrow indicates the beginning of the difference between the standard and the deviants. MMN was significant in the ‘c’ latency window (**– $p < 0.005$; * – $p < 0.05$). For the difficult contrast, the positive displacement of the difference curve was significant in the latency window 325–475 ms.

for each block and each contrast separately. Further, the two-tailed t-tests were used to verify the presence of the MMN response and positive deflections across the blocks and contrast types. ANOVA (Block × Frontality × Laterality) was used to compare MMN amplitudes across the blocks first and second in the latency window 'c' only, where the MMN responses to the easy contrast were significantly different form 0 μV at all electrodes. As the MMN to the difficult contrast was absent in the grand-average waveform in the first and the third blocks (Figure 2), the ERPs of the second block only were included in the statistical comparison. Another ANOVA (Contrast × Frontality × Laterality) was performed in order to see the effect of the phonological contrast type (easy vs. difficult) on MMN amplitudes.

Analysis of the Behavioral data

The NeuroScan Respwin program was used to perform an off-line analysis of the behavioral data including reaction times, hits, false alarms, and misses.

Results

ERPs to standard and deviant stimuli

The ERP changes across stimulus types and ERP blocks were largely confined to the N430 peak (Figure 3).

The standard N430 peak amplitude was significantly different from 0 μV at each recording site in each of the 3 blocks. The standard-N430 showed a significant Block effect [$F(2, 40) = 3.99$, $p < 0.035$]. The obligatory response became larger across the blocks (Figure 3). A least-significant difference post-hoc test showed that the effect originated from the difference between the first and the second blocks (−3.49 vs −4.54 μV, $p = 0.008$). The Block x Laterality interaction was significant ([$F(2, 40) = 5.70$, $p < 0.006$] in that the N430 amplitude was larger over the left than the right hemisphere in the second block (−4.72 vs −4.36 μV for the left and right hemispheres, correspondingly, $p = 0.001$), whereas in the first and the third blocks hemisphere differences were not significant.

Mismatch negativity

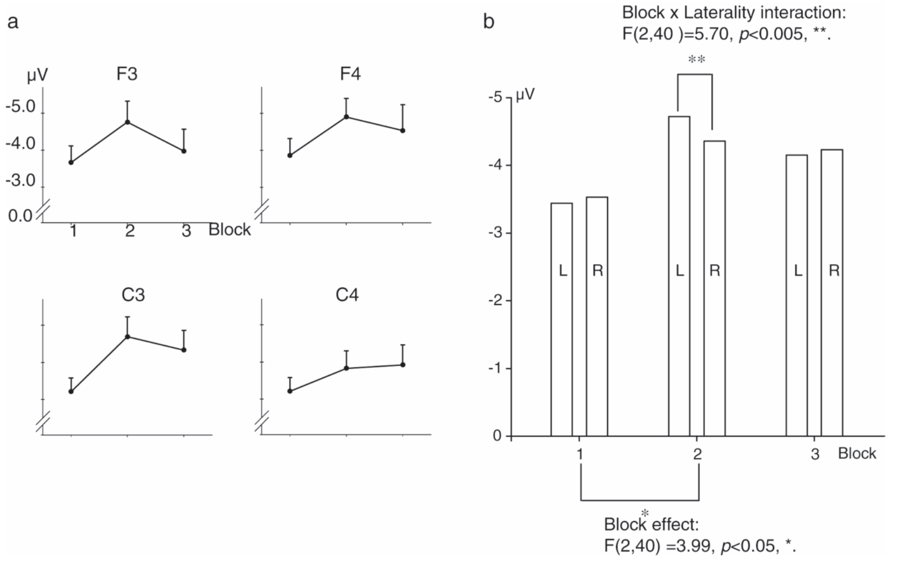
The easy contrast (as it can be seen in Figure 2) elicited a multi-peak MMN, whose magnitude was estimated in the three successive latency windows ('a', 'b', and 'c') (Figure 2, Table 1). A t-test for dependent variables showed that the amplitudes significantly differed from 0 μV in the third latency window (600–750 ms, or 430–580 ms from the difference onset) The difficult contrast elicited significant MMNs only in the 'c' window in the second block (Figure 2; Table 1).

A 3-way ANOVA for the easy deviant-minus-standard subtraction wave amplitudes revealed no significant block effect. The MMN response detected in the 'c' window did not reliably change across the experiment ($p = 0.24$).

In the first two blocks, the ERP response to the deviant was actually smaller than to the standard. This led to a positive deflection peaking in the window of 325–475 ms. This positive peak was significant at all the four electrodes in the third block. The response, however, was less consistent in the first and second blocks: (Table 1). Therefore, no ANOVA was performed to probe the Block effect.

Figure 3

The effect of repetition of the standard PW on the obligatory component of children's ERP



Note. (a) Mean amplitudes (μV) of the standard responses registered at F3, F4, C3, and C4 electrodes. Vertical bars indicate standard errors of mean. (b) The significant increase of the main response to the standard PW is seen in the second ERP block. In the same block, a left-hemisphere predominance for the N430 was observed. L and R indicate means of the amplitudes of the N430 at the left and right electrodes, respectively.

In a 3-way ANOVA, the difficult- and easy-contrast MMNs from the second blocks were compared. Neither Contrast effect nor its interaction with Centrality was significant (p = 0.61, p = 0.40). However, the Contrast type x Laterality interaction was significant: the left hemisphere MMN was larger for the easy than for the difficult contrast (−1.93–1.18 μV, p = 0.01).

Behavioral discrimination

In the first behavioral session the average percentage of hits for all 21 children was 32%. In the second session it increased to 39%, which was not significant. Moreover, only 12 subjects performed above the chance level for hits in either of the two behavioral discrimination sessions (none of them reaching performance level of 75% hits). On average, the children failed to discriminate between the standard stimulus and the difficult deviant in the active behavioral task even though all of them consistently correctly discriminated between the standard and the easy deviant in the practice session of the same design. Poor performance (below chance level) in the behavioral session across the subjects neither allowed us to observe a correlation between ERP's and performance

Table 1

Mean amplitudes (μV) of the negative and positive difference responses registered at F3, F4, C3, and C4 electrodes

		Easy-minus-Standard						Difficult-minus-Standard			
		1st MMN window		2dn MMN window		3rd MMN window		The window for positive deflection		3rd MMN window	
Block	Electrode	Mean amplitude (μV)	SE	Mean amplitude (μV)	SE	Mean amplitude (μV)	SE	Mean amplitude (μV)	SE	Mean amplitude (μV)	SE
1st	F3	−0.35 n.s.	0.39	−0.65 n.s.	0.41	**−1.36***	0.46	0.70*	0.30	–	–
	F4	−0.17 n.s.	0.44	−0.44 n.s.	0.44	**−1.37***	0.47	0.56	0.28	–	–
	C3	−0.50 n.s.	0.47	−1.27*	0.45	**−1.16***	0.46	1.16*	0.30	–	–
	C4	−0.32 n.s.	0.34	−1.13*	0.4	**−1.12***	0.36	0.02	0.25	–	–
2nd	F3	−0.64 n.s.	0.57	−0.47 n.s.	0.46	**−1.97***	0.46	0.63	0.44	**−0.92 n.s.**	0.48
	F4	−0.55 n.s.	0.55	−0.38 n.s.	0.47	**−1.93****	0.45	0.56	0.43	**−2.09***	0.39
	C3	−0.69 n.s.	0.58	−0.79 n.s.	0.53	**−1.88****	0.43	0.93*	0.42	**−1.43****	0.51
	C4	−0.96 n.s.	0.49	−0.60 n.s.	0.36	**−0.97****	0.30	0.88*	0.38	**−1.36****	0.39
3rd	F3	0.67 n.s.	0.45	−0.42 n.s.	0.58	**−0.88 n.s.**	0.56	1.35*	0.41	–	–
	F4	0.61 n.s.	0.53	−0.20 n.s.	0.52	**−1.17***	0.52	1.54*	0.40	–	–
	C3	−0.39 n.s.	0.54	−1.27 n.s.	0.65	**−0.88** n.s.	0.53	1.32*	0.37	–	–
	C4	0.19 n.s.	0.51	−0.80*	0.37	**−1.07***	0.39	1.38**	0.27	–	–

Note. MMN data for the easy and difficult contrasts are presented for the first, second, and third blocks separately. A different latency window was used to measure the positive deflection in the ERPs (marked in italic). SE indicates standard error of mean. Values marked in Bold were taken to ANOVAs.

*** $p < 0.0001$, ** $p < 0.005$, * $p < 0.05$, $^{n.s.}$ $p > 0.5$

scores, nor to compare ERPs of good (too few number) and poor performers.

Discussion

Central processing of auditory PWs as a function of exposure was studied using ERPs and perceptual discrimination of easy and difficult speech contrasts embedded in CVCV stimuli (/baga/ and /baka/) in 7–10-year-old children. The major negativity in the PW-elicited ERPs peaked at the latency of about 430 ms from stimulus onset. This obligatory ERP elicited by frequent stimuli showed an increase in amplitude across the blocks of the ERP experiment. In contrast, no enhancement of a discriminative brain response (MMN) to the rare stimuli was reliably observed. As this response is characterized as a subtraction between the response to the standards and that to the deviants, it could only get stronger if the response to the deviants grew more than the response to the standards during the experiment, or the response to the standards was attenuated while the response to the deviants stayed the same or got larger.

The increasing response to the standard PW seems to reflect consolidation, over the course of the experimental session, of the short-term representation of the repetitively presented PW. This process appears to occur in the left hemisphere as suggested by our finding that obligatory auditory ERP was larger in amplitude over the left than right hemisphere. The left hemisphere predominance was seen when the effect of the stimulus repetition on this typical children's response was the largest. In contrast, the few repetitions of the deviant PW apparently were not enough to support such a process – accordingly, no significant increase in the MMN was observed. Based on the observation of sensitization of the N200 response to repetitive auditory stimulation, Karhu et al. (1997) inferred an automatic build-up of neuronal representations in developing brain networks in school-aged children. Our finding of the enhancement of the standard-stimulus obligatory response is in line with this interpretation.

The easy deviant elicited a multicomponent MMN, whose peaks were measured over three successive time windows, while the difficult deviant elicited a significant MMN only in the 600–750 ms (430–580 ms from the difference onset) window. Moreover, for the difficult contrast, the MMN was preceded by a positive ERP. This positive deflection in the difference curve was obtained because the deviant ERP was positively displaced in relation to the standard response. This finding corroborates data reported by several authors (Pihko et al., 1999; Morr, Shafer, Kreuzer, & Kurtzberg, 2002; Čeponienė, et al., 2004) who found that ERPs to deviant responses might be more positive than that to the standard, especially in infants.

The results obtained in this study suggest that automatic auditory difference detection, as indexed by the MMN, was sensitive to the difficulty level of the discrimination: the easily detected deviant elicited the more negative response, resulting in the negatively displaced response (MMN), whereas the deviant response to the difficult contrast was smaller in amplitude and more positively displaced, thus resulting in the positive deflection in the difference waveform. Comparison of the easy- and difficult-contrast MMN responses showed a left-hemisphere predominance in discrimination of the easy-, but not the difficult-PW contrast. Though neither of the PW contrasts was specific to the subjects' mother-tongue, the easy PW however was less difficult to discriminate as compared with the difficult one; this may suggest activation (partial, at least) of language–specific memory traces during the easy-contrast discrimination (Näätänen, 2001). Although the /k/ vs. /g/ contrast is not part of Finnish phonology, it does occur in loan words and names.

In our study, the children's ability to actively discriminate the difficult contrast did not significantly improve during the behavioral experiment, nor did the MMN increase across the ERP sessions. Our initial expectation in this PW study was to observe an MMN enhancement as a result of perceptual experience along with (or even prior to) the improvement of behavioral performance in the active discrimination task. However, the present study showed no effect of passive stimuli exposure on the MMN response to the difficult stimulus. The behavioral task of the present study turned out to be too difficult for the 7–10-year-old children. Our results thus support the evidence obtained in previous studies: although speech perception in humans can be modified by relatively short-term auditory exposure (Kraus et al., 1995; Merzenich et al., 1996; Tallal et al., 1996; Tremblay et al., 1998; Shafiro, Sheft, Gygi, & Ho, 2012), such modification goes hand-in-hand with successful active behavioral discrimination and cannot be seen in its absence.

The multicomponent structure of the MMN to PWs recorded in our study is similar to that reported in some studies using speech stimuli (Cheour, Shestakova, Čeponienė, & Näätänen & Rinne, 2002; Schulte-Körne et al., 2001; Korpilahti et al., 2001; for review, see Näätänen et al., 2012). The results obtained in our study, showing that the easy contrast elicited the MMN with more than one pea\k, whereas the difficult one elicited a single-peak MMN, may suggest that the component structure of the difference waveforms depends on the degree of perceptual difficulty of the PW contrast.

Conclusion

Different dynamic behaviors of the obligatory (N430) and discriminative (MMN) responses were observed during the course of the experiment. The significant increase in the magnitude of the ERP to frequently repeated standard stimuli seems to reflect consolidation of the short-term representation of the repetitively presented PW, thus supporting the hypothesis of the automatic build-up of neuronal representations in developing brain networks in school-aged children. No such effect was observed in this study for the MMN, perhaps because of different time courses for learning effects on the frequent standards and the deviants. However, the results obtained in this study suggested that automatic auditory difference detection, as indexed by the MMN, is sensitive to the difficulty level of the discrimination: the easy-to-detect deviant elicited a more negative response whereas the deviant response to the difficult contrast was smaller in amplitude and included a positive displacement.

Acknowledgments

We thank Rita Čeponienė, (Project Scientist at University of California, San Diego) and Minna Huotilanen (Research Professor at Finnish Institute of Occupational Heath, Finland) for their help in data analysis and for editing the text. We also thank three anonymous reviewers for careful reading of the previous version of the manuscript and for their helpful comments.

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ЭЭГ-корреляты различения простых и сложных речевых контрастов в псевдословах у детей 7–10 лет

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Резюме

Были изучены психофизиологические аспекты обработки двух речевых контрастов, включенных в структуру псевдослов и различавшихся по сложности восприятия, в группе финских детей 7–10 лет. Для записи вызванных потенциалов (ВП) была применена классическая oddball парадигма, в качестве стандарта использовалось псевдослово /baka/, а в качестве двух девиантов – легкое для восприятия /baga/ и более сложное /bag*a/, которое звучало как среднее между /baka/ и /baga/. Способность детей активно различать более сложный контраст была изучена в двух отдельных поведенческих сессиях, которые чередовались с записями ВП. Увеличенная амплитуда наиболее негативного ответа на стандартный стимул, а не на девианты, предполагает формирование так называемого акустического шаблона для часто повторяющихся псевдослов в ходе эксперимента. Нами не было обнаружено достоверного влияния типа блока на амплитуду негативности рассогласования, которую можно рассматривать в качестве индекса автоматически формирующегося следа сенсорной памяти. Скорее, наблюдаемые эффекты указывают на развитие процесса консолидации следов памяти в ответ на повторно предъявляемые стимулы (псевдослова), чем на приобретаемые различия в дискриминации стимулов вне активного фокуса внимания, как это предполагает классический oddball. Данное предположение также подтверждается результатами проведенного поведенческого теста на активное различение псевдослов. Результаты нашего исследования не подтверждают предположения об автоматичности процессов научения различать сложный речевой контраст в отсутствие необходимости активной поведенческой дискриминации.

Ключевые слова: слуховые ВП, дети, негативность рассогласования (НР), псевдослова, перцептивное восприятие.