Physiol. Res. 54: 577-583, 2005

Visual Evoked Potentials and Event Related Potentials in Congenitally Deaf Subjects

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Received June 7, 2004
Accepted January 13, 2005
On-line available February 16, 2005

Summary

The purpose was to test parameters of visual evoked potentials (VEPs) and of event-related potentials (ERPs) in deaf subjects to verify visual and cognitive CNS functions in a handicapped group of the population. Three types of visual stimuli (with dominating parvocellular or magnocellular system activation or with cognitive tasks) were used in the study. Six deaf persons (4 women, 2 men, mean age 17 years) and 6 persons with normal hearing (sex- and age-matched) were included in this pilot study. In all types of stimulation, latencies and amplitudes of main VEPs and ERPs components were evaluated. No significant latency differences were found. However, significantly reduced amplitudes were found in the occipital area for responses to motion and cognitive stimuli which might be interpreted as a part of functional reorganization of the extrastriate and cognitive cortical areas of deaf subjects.

Key words
Sign language • Pattern-reversal VEPs • Motion VEPs • Event related potentials • Deaf subjects

Introduction

Sign language is an artificial language system that enables communication between normally hearing subjects and subjects with impaired hearing. It is based on gestures, body postures, face mimic and uses mainly visual stimuli with low contrast (Finney and Dobkins 2001). This offers one possible explanation for reported reorganization of CNS (strengthening of dorsal stream of the visual pathway) in persons with congenital deafness (Armstrong *et al.* 2002, Finney *et al.* 2003). However, it is also possible that due to the loss of information flow by means of the auditory pathway, attention is drawn to information transmitted by the visual system to a much greater extent. Normally, hearing also serves for the acquisition of information from the surrounding environment (periphery) and its loss can contribute to potentiating just that part of the visual pathway that analyses moving stimuli (low contrast movement) in the periphery. This is consistent with the fact that in deaf people moving stimuli which activate peripheral parts of the visual field yield a higher resulting response when compared to stimulation of the central retina. In normally hearing subjects it is actually just the other way round (Bavelier *et al.* 2000).

The aim of our pilot study was to verify some of the hitherto obtained specified information on changes of visual information processing in deaf people (with respect to the referred "cross-modal" sensory plasticity of the brain) and to evaluate the function of their visual system

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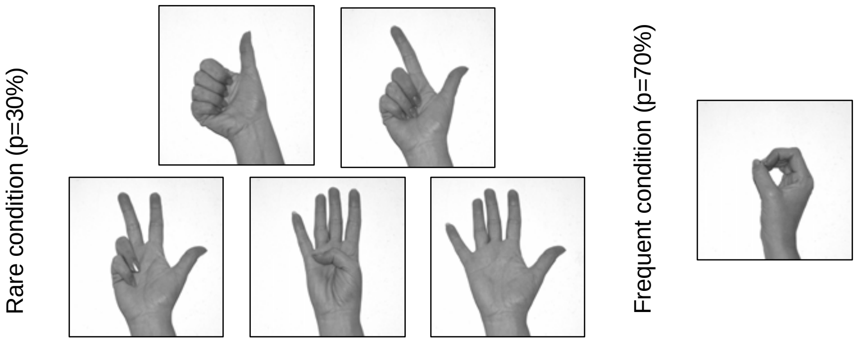
by means of objective visual evoked potentials (VEPs) examination. Since our system of electrophysiological testing of the visual functions is rather complex (pattern-related VEPs representing mainly parvocellular system activation, motion-onset VEPs reflecting magnocellular system activity and visual cognitive EP) (Kubová *et al.* 1996, 2002, 2005, Kuba *et al.* 1998, 2004), the study could compare possible consequences of deafness on various levels of cortical visual information processing. Objectifying suspected visual changes might also help in individual planning of education in subjects with hearing problems - mainly when some additional sensory deficit (such as dyslexia, see Samar *et al.* 2002) is present.

VEP is a non-invasive electrophysiological method that enables evaluate not only the condition of primary (Kubová *et al.* 1995) and secondary (Kuba and Kubová 1992) visual areas, but also the function of higher CNS areas. For testing of higher cortex centers, the method of visually evoked cognitive potentials (ERPs) (Brandeis and Lehmann 1986) can be used. This method has, however, several disadvantages – it is rather time-consuming, displays higher inter-individual variability compared to VEP (Polich 1998) and requires good co-operation with the tested person. In our study, we aspired, by stimuli development, to elicit ERPs that have quite low inter-individual variability and are adequate for deaf people.

ERP stimuli type B



ERP stimuli type C

Fig. 1. Stimuli for the B and C ERP tasks. To assess possible differences in processing of sign language between deaf subject (experienced) and control subjects (no knowledge), special stimuli were designed. The B stimulus represented translation of counting Arabic digits (A stimulus) into sign language with restriction of the maximal digit value to 5. The subjects were asked to count sum of the fingers and to report it at the end of the stimulus session. The C stimulus, more specific for the sign language, represented a rare condition as a sign without any meaning in the sign language, while four variants of the frequent condition showed common meanings: 'girl', 'good', 'me' and 'friend'. These signs were chosen because they can be understood even when they are in static presentation (photo). Sign language teacher was posing for the photos. The pictures were presented in color and subtended 23x23 deg of the central visual field

Methods

We tested six deaf subjects (4 women, 2 men) in the age span of 16-18 years. All of them had a congenital hearing disorder, above-average IQ and a good knowledge of sign language. The control group consisted of 6 age-matched healthy volunteers (4 women, 2 men). All subjects in both groups had normal visual acuity and no visual system disorder.

The stimuli were generated using our own software (Kremláček *et al.* 1999) on the 21” monitor Iiyama with 60 Hz frame frequency and mean luminance of 17 cd/m^2.

Three types of visual stimuli were used. The first one, activating primary visual areas, was pattern-reversal of black/white checkerboard with an element size of 40’ (R40’) and 20’ (R20’) (96 % contrast according to Michelson, reversal rate 2 cycle/s). The second type of stimulation was represented by two variants of moving stimuli that are supposed to activate associate visual areas in the medio-temporal cortex (Tanaka and Saito 1989).

"M-10" consisted of linear motion of low contrast 40‘ checks (velocity of movement 10 deg/s); "M-rad" consisted of radial movement of concentric frames (spatial frequency of 1-0.2 c/deg, velocity of movement of 10-23 deg/s). Due to this arrangement (spatial frequency decrease and velocity increase towards the periphery) this stimulation evoked higher amplitudes of the main negative peak in comparison with the M-10 stimulation.

In both stimuli patterns of 10 % contrast were used, which seems to be advantageous for a more selective activation of the magnocellular system of the visual pathway terminating in extrastriate areas (V3, MT – V5) (Kubová *et al.* 1995). The structure moved for 200 ms and for one second it was stationary.

The last type of stimulation consisted of three modifications of cognitive tasks for the ERP testing:

A) Randomly appearing Arabic digits alternated with the letter X. The digits 1-9 represented the “rare” stimulus, X letter the “frequent” one. The size of digits and the X letter was 5.7 x 6.3 deg. The tested subject was asked to make a sum of the displayed digits and to say the result at the end of a set of stimuli. This arrangement ensured concentration and motivation of subjects without the need of any motor action for signaling of the rare stimuli, which can contaminate ERPs by additional potentials generated in the motor precentral cortex.

B) Counting of fingers (Fig. 1) – the appearance of 1-5 fingers represented the rare stimulus, as the frequent one zero in the sign language was displayed. Cognitive task was the same as in the previous stimulation – adding of fingers and announcement of the result at the end.

C) Discrimination between one sign that has no meaning in the sign language (rare stimulus) and one of four signs that have a particular meaning in the sign language (frequent stimuli) – the signs were shown to subjects prior to the experiment. The task was to count the number of rare stimuli. The stimuli were taken from color photographs of a person demonstrating sign language (Fig. 1). This cognitive task does not represent the typical „odd-ball paradigm” as the previous ones because of four types of the frequent stimuli.

In all cognitive stimuli, the probability of rare and frequent stimuli was 30 % and 70 %, respectively. The stimulus duration was 600 ms and a blank field was presented in the interstimulus intervals lasting 500 ms. In ERPs the latencies and inter-peak amplitudes of the positive P300 peak were evaluated.

Binocular VEPs and ERPs were recorded in unipolar derivations O_Z, O_L, O_R (5 cm right or left from O_Z), P_Z, C_Z, F_Z with the reference electrode placed on the right earlobe. After amplification (20 000 *x*), analog filtering (band-pass 0.3-45 Hz) was applied (Contact Precision Instruments Ltd., UK). 40 sweeps of 440 ms (with 500 Hz sampling frequency) were averaged in both types of VEPs, while 20 sweeps of 1 s (250 Hz sampling frequency) were recorded for the ERPs and averaged in each task condition.

At the end of each experiment 64 s recordings of resting EEG with eyes closed were also made (sampling rate of 100 Hz) for off-line frequency analysis. Sixteen periodograms were computed (using Fast Fourier transformation in 4 s epochs) and averaged.

All recordings were performed in a sound-attenuated, electromagnetically-shielded chamber with background luminance of 1 cd/m^2. Subjects were seated in a comfortable dental chair with neck support to reduce head movements and muscle artifacts. A fixation point was placed in the center of a stimulus field and subjects were instructed not to follow the moving patterns with their eyes and not to blink in cognitive stimuli. Correct fixation was monitored with an infra-red CD camera. In case of artifacts (most frequently related to eye blinking) the whole recording was repeated or offline visually inspected with rejection of the contaminated sweeps.

Statistical analysis of the recordings was based on detection of signal differences in the deaf and control groups by means of the Student’s t-test of factor scores for the first principal components – PC1 (Achim 1995) was. All recorded derivations were tested in particular time intervals dependent on the stimulus type. The most interesting interval for VEPs was from 50 to 300 ms. For the cognitive ERPs, the interval from 100 up to 600 ms was selected according to the main latencies of the components. The exact time of existing differences was determined by point-wise tests of the mean (t-test for unequal variances) with alpha level of 0.05.

Table 1. Mean latencies [ms] for pattern-reversal (R40', R20'), motion-onset (M-10, M-rad) and visually evoked cognitive potentials (ERP A, B, C).

		R20'	R40'	M-10	M-rad	ERP A rare	ERP B rare	ERP C rare
Control group	mean	105	104	159	150	389	427	439
	SD	8.7	5.2	9.1	16	25.1	42.6	24
Deaf people	mean	109	105	165	159	373	411	431
	SD	5.1	6.1	12.2	12.4	29.6	30.4	16.2

Since the used method does not allow direct comparison of the latencies, we also extracted these parameters of dominant peaks. For the pattern-reversal response the latencies of main P100 peak were evaluated in the O_Z derivation. In the motion-onset VEPs the main negative (N160) peak was tested in O_L or O_R derivations (selected according to the amplitude maximum) and for ERP P300 latency in C_Z derivation was used (Table 1). Group differences were evaluated by means of the non-paired t-test, the paired t-test was used for comparisons within one group (rare vs. frequent or different types of the ERPs). Because of the small number of subjects, the t-test results were verified by using the Kolmogorov-Smirnov non-parametric test (MATLAB v.6 and Statistica v.6).

Results

The group grand averages of the pattern reversal VEPs with standard deviations for deaf and control groups are depicted in Figure 2. The PC1 comparison did not show any significant differences in the primary visual area (occipital derivations). Responses to both motion stimuli (Fig. 2) exhibited significantly larger motion-specific negativity in control subjects in O_Z and O_R derivations.

The grand-averages of cognitive ERP type A (number summation) for frequent and rare conditions are shown in Fig. 3. While responses to rare (upper panels) and frequent (lower panels) stimuli yielded a high variability, especially in the early primary sensory response, the comparison of frequent-rare ERP difference (Fig. 4) (with suppressed variations) displayed a significantly smaller P300 wave in the group of deaf subjects. The PC1 test confirmed its statistical significance surprisingly in O_Z and O_R derivations only. The assessment of the ERP type B yielded a similar pattern as in the ERP type A (Fig. 4). Significant differences were again observed in O_Z and O_R derivation only. Unlike the previous ones, the ERP type C did not exhibit any significant differences between deaf and control subjects.

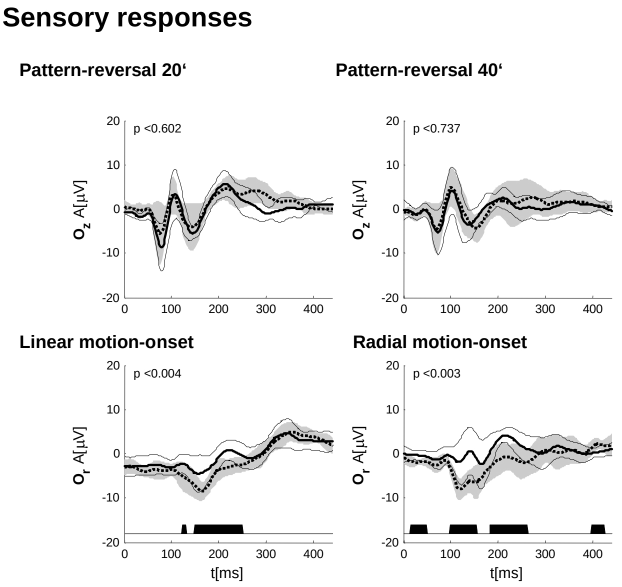


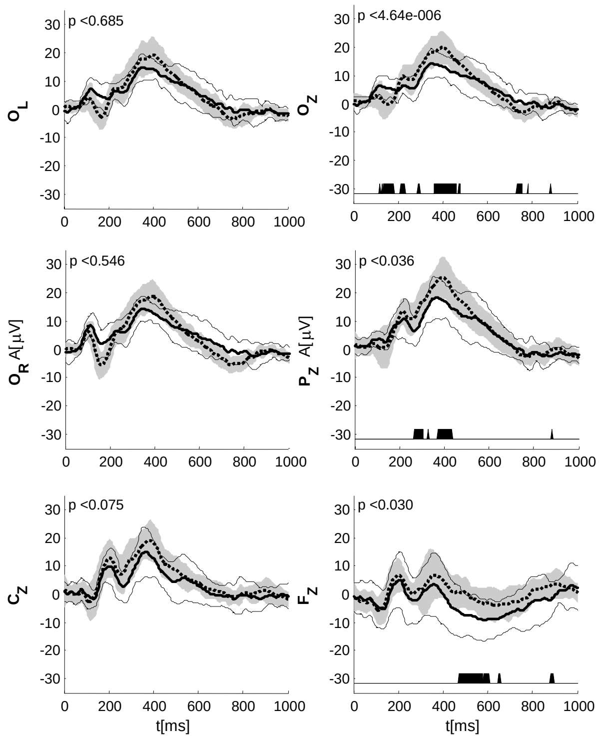
Fig. 2. Group mean responses to pattern-reversal (R20', R40') and to motion-onset stimuli (M-10, M-rad). The grand averages ± standard deviations are plotted for the group of deaf subjects as solid lines, for the control subjects the ± standard deviation area is drawn as a gray patch in the background and the grand average is plotted as a dotted line. The overall difference in the interval 50-300 ms (tested by the PC1 method) is expressed as the "p" value in the left upper corner of each box. Results of point-wise comparisons are depicted in the bottom of the box as upward black deflections. Differences between deaf and control subjects for motion-onset stimuli were significant in the O_R derivations (around the dominant negative peak N160).

A difference was also observed in the primary (sensory) part of the ERPs, which was present uniformly in all three types of ERP (in both rare and frequent conditions and in all occipital derivations (O_R, O_L and O_Z). The group of normal subjects displayed a larger negativity peaking at 160 ms (Fig. 3).

When the three ERP variants were compared, the ERP to counting of fingers in the deaf group exhibited comparable latency as the ERP to counting of digits. However, the control group had longer latencies for counting of the fingers. In both groups the ERP variant C (discrimination of meaningful signs) displayed longest latencies (Table 1).

Testing of the EEG frequency spectra did not show any significant difference between the normally hearing and deaf subjects (dominant frequency: deaf 10.1±0.94 Hz, controls 9.9±0.45 Hz; percentage of alpha activity: deaf 61.0±19.2 %, controls 67.0±4.6 %; theta activity: deaf 13.0±6.7 %, controls 11.0±2.4 %; beta activity: deaf 9±5.0 %, controls 8±4.5 %).

ERP Type A – rare condition



ERP Type A – frequent condition

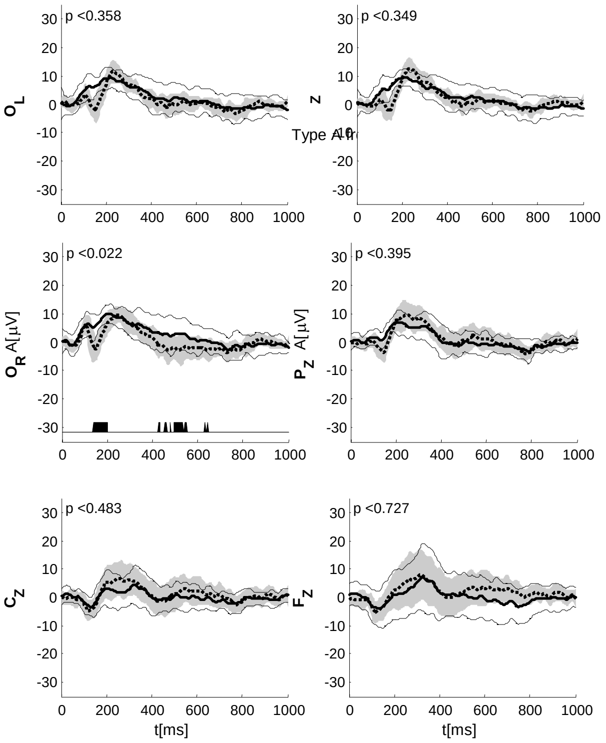


Fig. 3a, b. Group mean responses to number summation - ERP task A. Responses to rare (upper panels) and frequent (lower panels) conditions are presented. The presentation is as in Fig. 2. Statistical significance ("p") assessed by PC1 is related to the time interval from 100 to 600 ms. The most systematic and significant change is the smaller P300 wave (O_Z and P_Z derivations) in the deaf group (upper panels).

Cognitive responses (Frequent-Rare condition)

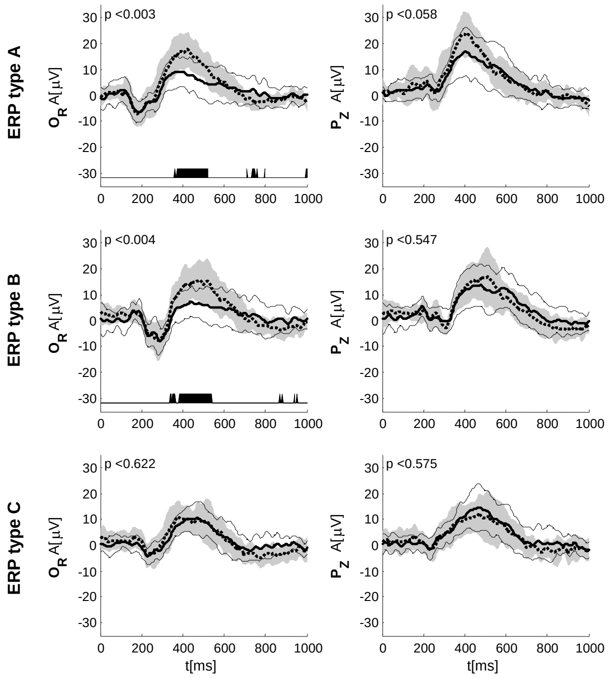


Fig. 4. Group mean responses in ERP type A, B and C. The differences between rare and frequent conditions to all cognitive stimuli are shown for number summation (A) – the first row, finger summation (B) – the second row and nonsense symbol presentation (C) – the last row. Only responses from O_R (left column) and P_Z (right column) derivations are depicted here (derivations with major differences between groups). Solid thick lines are used for means, thin lines for ± standard deviations in the group of deaf subjects. In the control group dotted lines represent means and gray patch is used for ± standard deviation.

Discussion

According to the evaluation of latencies, visual information processing in hearing disabled subjects is comparable to the controls. However, the extended analysis of amplitudes showed a significant difference in the strength of the activation among these two groups. The motion-onset responses were smaller in deaf subjects in occipital derivations, especially in the right occipital region. This observation might support the hypothesis of a reorganization of the brain, most likely in the frame of cross-modal cortical plasticity described by Neville and Lawson (1987).

However, our findings are not in agreement with the results of Armstrong *et al.* (2002) reporting N160 amplitude increase in a group of deaf subjects for motion in the central and peripheral parts of the visual field. The opposite findings might be explained by a difference in the applied performed stimuli. In the mentioned paper the stimulus subtended only 2x2 deg and fine (9 c/deg) vertical gratings moving at high temporal frequency of 13.7 cycles/s were used – in contrast to our larger (37 x 28 deg) stimuli of temporal frequency 5 cycles/s for M-rad and 3.75 cycles/s for M-10. Since the temporal frequency can strongly influence the response characteristics (Kuba and Kubová 1992), the findings of Armstrong *et al.* (2002) need not reflect adequately the activity of the magnocellular system.

The finding of smaller P300 amplitudes of ERPs to cognitive tasks type A and B observed mainly in the occipital region of deaf subjects is difficult to interpret. The drop of their amplitudes cannot be described as direct potentiation or attenuation of visual processing compared to the control group (neural basis of the differences is unknown and no differences in P300 latencies have been found).

The only evidence for enhancement of visual processing in deaf subjects is the fact that they did not display prolonged P300 latency in counting of fingers compared to digits. This might mean that the “fingers” are not such a familiar stimulus for controls as for the deaf (in whom the every day use of the sign language strengthens the cortical areas that are responsible for this kind of information processing). The longest P300 latencies of the C variant in both groups can be explained by the different paradigm used (4 types of frequent and one rare stimulus).

The two groups further differed in velocity of cognitive tasks processing based on use of fingers. Whilst the normal subjects clearly preferred the information given in written Arabic digits, this was not found in deaf subjects who master the sign language. We plan an extension of this study to prove that event-related potentials might be used as a tool in the deaf to prove objectively their ability to cope with the sign language.

Acknowledgements

This work was supported by a Grant from James S. McDonnell Foundation for Cognitive Neuroscience of USA (No. 99-57EE-GLO.04) and by the Grant Agency of the Czech Republic (grant 309/02/1134).

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Reprint requests

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