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Global Brain Dynamics of Transient Visual Evoked Potentials

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Summary

The independent component analysis was applied to multichannel transient visual evoked potentials elicited by a high contrast pattern-reversal and motion-onset (motion velocity of 7 and 23 deg/s). Three overlapping independent components with different topographical distribution over the scalp were described. The first component displayed similar timing in response to all three stimuli (40-200 ms) but was a different in shape and scalp projection. This activation component is considered to reflect the stimulus properties. The second component (100-227 ms), related to negativity at about 160 ms, can be referred to visual processing of motion. The last component, attributed to positivity at 230 ms dominates in the fronto-central area and might represent a cognitive process.

Key words
Visual evoked potentials • Visual motion stimulation • Independent component analysis • Motion processing.

Introduction

Transient visual evoked potentials (VEPs) are being used for a long time as one of the most important neuro-ophthalmological examinations (Harding *et al.* 1996). The standard testing of the ventral (parvocellular) stream of the visual pathway comprises pattern-reversal stimulation (P-VEPs). In our laboratory, we have additionally introduced an examination of the dorsal (magnocellular) stream (Ungerleider and Mishkin 1982) in response to motion stimulation (M-VEPs) (Kuba and Kubová 1982, Kubová and Kuba 1982).

The traditional VEPs examination employs several electrodes placed over the occipital region with an arbitrary reference electrode (Fz, ear lobe, mastoid, zygoma). The evaluation of VEPs is usually aimed to describe the peak latencies and amplitudes in the occipital recordings. However, an enlarged set of recording sites over the head displays shorter P-VEPs and M-VEPs latencies in the parietal, central and frontal leads. Therefore, we tried to explore the spatio-temporal properties of P-VEPs and M-VEPs.

A new branch of statistical multichannel data processing has been introduced which is intended to decompose a linear mixture of sources into independent components without any prior information about the process (named blind source separation). There are several methods of studying this blind source separation such as the traditional Principal Component Analysis, Factor Analysis and a recently developed Independent Component Analysis (ICA) (Lee *et al.* - in press). The ICA has been used to reveal independent sources of auditory event related potentials (Makeig *et al.* 1997). The ICA results are not only non-correlated, but they are also independent in terms of higher order correlation. For this reason we used the ICA to explore multichannel visual evoked potentials.

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Methods

A group of 4 healthy subjects (2 women, 2 men) with no visual or neurological disorders in the past was examined. Informed consent with the experiment was obtained from each of subject.

The stimulation was conducted by means of our stimulation software (Kremláček *et al.* 1999) and it was displayed on a 21' computer monitor ViewSonic (USA) with 75 Hz frame frequency and mean luminance of 17 cd m^{-2}. The stimulation field at 0.5 m observing distance subtended 45x35 deg.

For the parvocellular system stimulation, a checkerboard pattern-reversal (98 % Michelson contrast) with check size of 40 arc min (i.e. spatial frequency of 0.75 deg^{-1}) was used. Because of two reported ways of motion processing (Ffytche *et al.* 1995) in man, we prepared two variants of motion stimuli. To examine the slow geniculo-striate channel, we used high contrast (96 %) checkerboard (0.75 deg^{-1}) moving at a velocity of 7 deg/s. Low (10 %) contrast isolated checks of 40 arc min with a period of 0.375 deg^{-1} and motion velocity of 23 deg/s were used for rapid (tectal) channel examination. In the case of both stimuli, there was 0.5 s of motion and 2.5 s of stationary structure presentation. The pattern moved in one of four fundamental directions in a pseudo-random order.

The VEP data were recorded from the following eight unipolar leads: F3, F4, C3, C4, Pz, Oz, Ol and Or (5 cm to the left or right from Oz) with the right ear lobe - A2 as reference. The signal was amplified 20 000 times and filtered with a band pass filter 0.1 to 100 Hz by an EEG amplifier (Contact Precision Instruments, UK). Twenty sweeps were digitized (256 samples at 250 Hz from 8 leads) by an AD-converter (Data Translation – USA) and averaged by an IBM PC – Pentium II to eliminate spontaneous non-correlated activity. Three such sessions were recorded in each subject and stimulus, condition and averaged to further increase the signal-to-noise ratio. The contribution of each subject was averaged in the group and a normalized group grand average for each stimulus condition was computed.

The grand averages were analyzed by the ICA method (Makeig *et al.* 1997) in Matlab v 5.1 (USA) to minimize the mutual information among newly computed components - "activations". The grand average 'x' (matrix of samples x columns) was decomposed by a general transformation formula

$$x = W s,$$

where 'W' is the decomposing (unmixing) matrix and 's' denotes the original sources – "activations" which could represent simultaneously activated different cortical areas. To assess the most contributing components, variance and normalized mean square root error between the measured and reconstructed data were computed. The 'e' denotes an estimate of the original data.

$$NRMSE = Sqrt(sum((x-e)^2)/sum(x^2))$$

Results

The results are summarized in Figs 1-3 with the following general arrangement. The EP data are given in the first column, the independent components – "activations" – are in the second column. Maps of particular activation distributions over the head are displayed in the third column. The first four "activations" (five in case of slow motion) were chosen according to the proportion of explained EP variability and they were sorted out with respect to the incidence of their maximum from top to bottom. The signal reconstructed from these "activations" is depicted as the red curve in the "data" column. The activation polarity is arbitrary on the ICA output and it was therefore reorganized to be consistent with the original data at the point of the maximal contribution. It is shown in the map on the right side how a particular activation component contributes to the data. The time in the left bottom corner of the map describes the timing of the activation extreme. The activation's extreme marked as zero indicates that this "activation" was not included in the reconstruction because its contribution was negligible.

Pattern-reversal

Grand average VEPs recorded to pattern reversal stimulation are displayed in Figure 1. The signal was reconstructed from the first four "activations" with NRMSE=0.27. The first "activation" (displayed in the middle column "act") is very closely localized in the central parieto-occipital area (Oz, Pz) with the onset of rapid oscillations at 34 ms. The oscillations take about 130 ms with negative peaks at 68 ms (corresponding to N75 usually marked in P-VEPs) and at 119 ms. The very narrow peak at 87 ms with opposite polarity corresponds to P100. The second "activation" displays a negativity peaked at about 148 ms after the stimulus onset. This negativity commonly marked as N145 is distributed over a larger area than the first one. The third "activation" has

a maximum in the positive peak at 236 ms. This activation is localized in the fronto-central region. The fourth "activation" over the central region has a maximum at 332 ms.

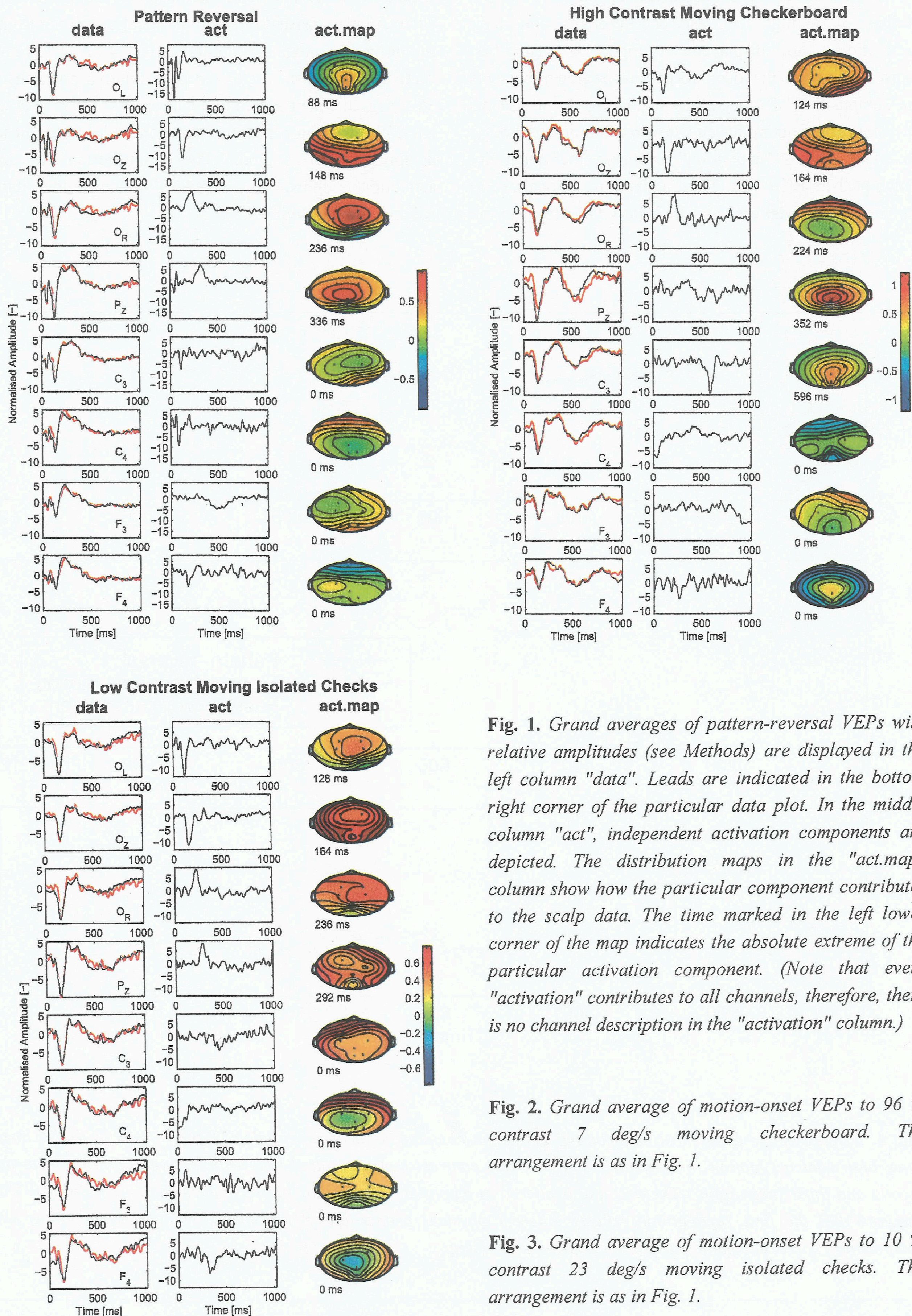

Fig. 1. *Grand averages of pattern-reversal VEPs with relative amplitudes (see Methods) are displayed in the left column "data". Leads are indicated in the bottom right corner of the particular data plot. In the middle column "act", independent activation components are depicted. The distribution maps in the "act.map" column show how the particular component contributes to the scalp data. The time marked in the left lower corner of the map indicates the absolute extreme of the particular activation component. (Note that every "activation" contributes to all channels, therefore, there is no channel description in the "activation" column.)*

Fig. 2. *Grand average of motion-onset VEPs to 96 % contrast 7 deg/s moving checkerboard. The arrangement is as in Fig. 1.*

Fig. 3. *Grand average of motion-onset VEPs to 10 % contrast 23 deg/s moving isolated checks. The arrangement is as in Fig. 1.*

High contrast moving checkerboard

Grand average responses to slow (7 deg/s) motion of a high contrast checkerboard and their "activations" are displayed in Figure 2. The first "activation" over the occipito-parietal region represents the composition of a negativity appearing about 124 ms after onset of the stimulus and slow oscillations at about 2 Hz. The second "activation" concerns the negativity which peaked at 164 ms. This "activation" is localized in the parieto-occipital area and is slightly lateralized to the left hemisphere, where all subjects displayed an increase in amplitude of the dominant negative peak. The third "activation" consisted of positivity localized in the frontal region with a maximum amplitude at 224 ms. The fourth "activation" was characterized by a relative positivity at 352 ms in the central and parietal regions. There is still a late (596 ms) sharp negative component localized in the occipito-parietal region. The contribution of the activation is shown by the red solid line in the "data" column with NRMSE=0.25.

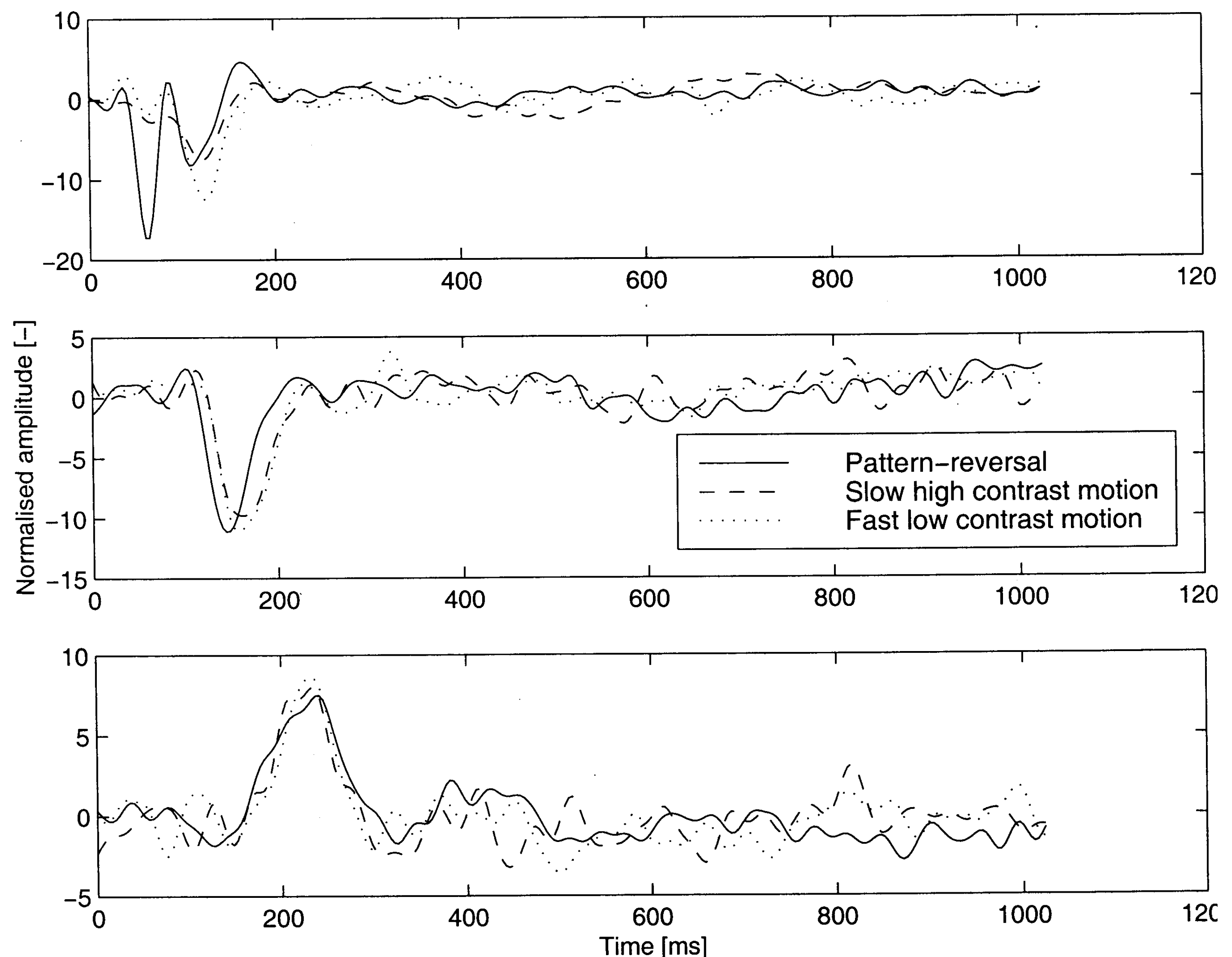

Fig. 4. *Display of the three most contributing activation components in three subplots. Pattern-reversal (solid line), slow, high contrast motion (broken line) and fast, low contrast motion (dotted line) express high correlation in the second and third "activation". The first one is altered in amplitude, but similar in phase during the first 200 ms. This suggests that the first "activation" reflects different physical properties of a stimulus, while the remaining two components represent common visual information processing.*

Low contrast moving isolated checks

Grand average responses and their independent components recorded to 23 deg/s motion-onset are illustrated in Figure 3. There, the first three "activations" were very similar to those presented in the slowly moving high contrast checkerboard. But there are some differences in their arrangement. The first "activation" is directed more towards the frontal region and it does not carry the slow oscillation of 2 Hz. The second "activation" is not lateralized as in the previous case and it is also more diffuse and concentrated in the frontal area. The fourth "activation" dominates in the parietal and central areas at 292 ms. The reconstructed data describe the original signal with NRMSE=0.38.

Discussion

The first "activation" displayed differences in timing of the maximum amplitude among the used stimulation. While VEPs negativity dominated at 69 ms in the pattern-reversal, in the cases of slow and fast motion-onset, this "activation" dominated by a negative peak at 124 ms. In spite of different dominant peaks, the frequency of the fast oscillations (15 Hz) and its phases were the same for all three "activations" (see Fig. 4 - first row). We could thus hypothesize that there is a sum of constant generators involved in VEP generation (visual processing) with a different input for particular stimulation parameters. The contribution of this "activation" to pattern reversal and slow motion was maximal in the occipital region but the fast low contrast motion had its maximum localized in the fronto-central area. This might be due to extrastriatal propagation *via* the tectal pathway. Such extrastriate "activations" related to motion perception have been reported (e.g. Ffytche *et al.* 1995, 1996). The early onset of these "activations" (about 40 ms after the stimulus – in agreement with Ffytche *et al.* 1995, Buchner *et al.* 1997) supports the evidence that the first component reflects different physical properties of the stimulus.

We found that there was a distinct similarity in the next two activation components in responses to all stimuli. The second "activations" (Fig. 4 – the second row) dominated by a negativity at about 160 ms. This peak corresponds to N145 reported in pattern-reversal VEPs and to N160 reported in the motion-onset VEPs (Kuba and Kubová 1992, Kubová *et al.* 1995). "Activations" were lateralized into the left hemisphere and were distributed widely from the occipital to the central area. In the case of fast motion, this "activation" even reached the frontal brain cortex. Furthermore, the third significant "activation" displayed a high similarity among all stimuli (see Fig. 4 – the third row). Since the two latter "activations" exhibit similar behavior irrespective of the stimulus parameters. This might represent a common approach to motion processing (the pattern reversal can be interpreted as very fast motion with an arbitrary direction).

For the pattern-reversal VEPs and the slow high contrast motion responses, there was demonstrated propagation of the electrical activity from the occipital region – V1 (first "activation") to extrastriatal areas – V2, V3, V3a, MT, MST (second "activation") and subsequently also into the fronto-central region (third „activation“). This finding is in good agreement with the hypothesis of visual information processing reported by Ungerleider and Haxby (1994).

The ICA method also has its limitations. If there is a single traveling wave without a constant localization, then the ICA decomposes this wave into two components, the timing of which corresponds to the onset and offset of "activation". Simultaneously, there is overlapping in the space localization of these components. Thus, we would suggest that a double negativity in the motion responses can represent a certain splitting of the moving wave. However, we can compare the velocities of the wave propagation across the head. For the particular case of low contrast motion-onset VEPs, the propagation from Cz to Pz (distance of about 0.07 m), which takes 36 ms, corresponds to the conduction velocity of 1.9 m/s. This is rather a low value when compared to the typical conduction velocities in man (7-11 m/s - Nunez 1981). From this point of view, the possibility of a moving wave seems to be unlikely.

Conclusions

The ICA method was applied for evaluating transient motion-related VEPs. It was shown that these responses have some common electrophysiological characteristics of visual information processing, despite differences in physical parameters of the used stimuli and different parameters of single electrode recordings.

For pattern reversal, high contrast low velocity motion and low contrast high velocity motion, three dominant "activations" have been reported. The first describes the early sensory information starting at 40 ms and oscillates up to 200 ms, with variations among the tested stimuli. The next "activation", describes associated sensory processing in the parietal region and starts at 100

ms and lasts up to 227 ms. The third one activates the fronto-central cognitive areas from 150 to 300 ms after onset of the stimulus.

For the low contrast high velocity motion, early "activation" in the fronto-central area was additionally reported (starting at 40 ms and displaying maximum negativity at 128 ms).

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