Documenta Ophthalmologica (2004) 109:169–175

Motion-onset VEPs to translating, radial, rotating and spiral stimuli

Jan Kremláček, Miroslav Kuba, Zuzana Kubová & Jana Chlubnová
Charles University, Faculty of Medicine in Hradec Králové, Czech Republic

Accepted 23 September 2004

Key words: motion-onset VEPs, radial motion, rotation, spiral motion, translating motion

Abstract

Motion-onset related visual evoked potentials (M-VEPs) were recorded as a result of the three basic (translating, radial and rotating) and one complex (spiral) motion stimulations in five subjects. Low contrast, retinotopically scaled patterns evoked potentials with major motion-onset specific negativity N160 with maximum in the parieto-temporal region. All multidirectional motion stimuli elicited the motion-onset response of significantly higher amplitude and shorter latency compared to the translating (unidirectional) motion. The rotation-onset evoked potentials had significantly shorter latencies than the rest of explored stimuli. The most stable responses with the largest N160 amplitude were recorded to the radial motion. After masking of the central 20° of the visual field these motion-onset VEPs were acquired without statistically significant amplitude drop. The efficiency and usefulness of the radial stimulus is presented in two clinical cases.

Abbreviations: avg – average; CMF – cortical magnification factor; ERPs – event related potentials; ISI – interstimulus interval; M-VEPs – motion-onset VEPs; MEG – magnetoencephalogram; MSTd – middle superior temporal dorsal area; MT – middle temporal area; SD – standard deviation; V1 – primary visual area; V3 – third visual area; VEPs – visual evoked potentials

Introduction

Efforts to extend facilities of visual evoked potentials (VEPs) – the low cost and non-invasive electrophysiological examination of the visual and central nervous systems – and to increase their sensitivity and specificity lead to enlarging of the so far used set of visual stimuli. The traditional pattern-reversal stimulus is oriented toward examination of the primary visual area (V1) and it is closely dependent on a high contrast and good visual acuity. This pattern-related stimulus should be effectively supplemented by stimuli targeting some other visual cortical areas. A motion-onset in the visual field, activating the dorsal visual stream, is rather independent of visual acuity [1] and contrast [2] and together with the pattern-reversal it might be the optimal stimulus combination for a wide range of neuro-ophthalmologic diagnostics [3]. In spite of the high interest paid to this field [4–13], so far there are not sufficiently established motion stimuli for the clinical diagnostics. Such stimuli must be enough effective for activation of the appropriate (extrastriate) visual areas and simultaneously the resulting evoked potentials should have a low inter-individual variability and acceptable total examination time. Stimuli used in 'single unit studies', which are more specific to behavior of single motion sensitive neurons within the 'dorsal stream', are not generally applicable for evoked potentials since they do not fulfill the specified conditions and they are usually efficient only in a group statistics. However, there are studies of complex motion, which point out superiority of the optic flow stimuli composed from radial, translating and rotating motions. The radial motion is subjectively

perceived as faster compared to translating [14] or rotating ones [15] and the human speed sensitivity is higher for radial and circular optic flow components [16]. Stimuli based on activation of the MSTd neurons with large receptive fields up to 72° [17] could bring valuable objective information about peripheral vision not tested with standard VEPs yet. Further, the magnetic evoked fields recorded to radial motion exhibited higher amplitudes [18] and there is also study where radial motion was used to elicit steady-state motion response [19].

Therefore, in our search for the optimal stimulus, to enlarge the VEPs standard examination and to make it more sensitive, we evaluated effect of the optic flow components [20] and of the complex motion onto the M-VEPs generation. We tested the following types of motion: radial (expansion/contraction), rotation, spiral motion and translating motion of vertical gratings. The goal was to find a motion stimulus evoking cortical response with large amplitude and low interindividual variability of latencies for clinical diagnostics.

Methods

Subjects

A group of five healthy adult subjects participated in this study (3 men; aged 22–49 years, 2 women; 25 and 41 years). They had neither ophthalmologic nor neurological abnormalities. A written informed consent was obtained from every subject before the examination procedure.

Stimuli

We used six kinds of motion stimuli: (1) Vertical grating moving left or right (translating motion); (2) Windmill (with 24 segments) rotating to the left or right (rotation motion); (3) Circular pattern expanding/contracting (radial motion); (4) Spiral pattern combining rotation (left–right) and expansion/contraction (spiral motion); (5) Stimulus No. 2 with central 20° masked (peripheral rotation); (6) Stimulus No. 3 with central 20° masked (peripheral radial motion). All stimuli were corrected for equal visibility in the whole stimulus field by a magnification factor [CMF = 1/(0.1*eccentricity + 1)]. Since the temporal frequency of 5.1 $c \cdot s^{-1}$ was kept constant over the whole stimulus field, consequently the local motion velocity was increasing (5–25 $deg \cdot s^{-1}$) while spatial frequency was decreasing (1–0.2 $c \cdot deg^{-1}$) toward the periphery. For particular relationship of the spatial frequency to the eccentricity see the Figure 1.

The mean luminance of 17 $cd \cdot m^{-2}$ was modulated in all stimuli by a sinusoidal function so that the maximal Michelson contrast was 10%. The low contrast was used to make the responses more specific for magnocellular system [2,13,21]. The particular structure moved for 200 ms (in random sequence of directions) with stationary structure presented for 1000 ms (interstimulus interval – ISI). The stimuli were presented on the 21″ computer monitor (Vision Master Pro 510, Iiyama Japan) subtending 37° × 28° of the visual field from 500 mm of the observing distance. The monitor was driven using the Visual Stimulus Generator 2/5 (CRS ltd., UK) at 105 Hz of vertical refresh frequency.

Recordings

VEPs acquisition was performed in darkened, sound attenuated, electromagnetically shielded room with the background luminance of 0.1 $cd \cdot m^{-2}$. During the experiment the subjects have been sitting in a comfortable dental chair with a neck support to reduce muscle artifacts and they were instructed to fixate visually the marked center of the stimulus field and not to follow the moving pattern. The correct fixation was monitored via infrared CCD camera located in the acquisition room. 40 EEG sweeps of 500 ms duration were recorded from 15 unipolar derivations (O3, OZ, O4, T5, T6, P3, PZ, P4, C3, CZ, C4, F3, F4, FP1 and FP2) with the right earlobe reference. The recording was made binocularly and twice for each stimulus condition. After amplification in the frequency band 0.3–100 Hz (Contact Precision Instruments – PSYLAB, System 5) the signal was sampled at 500 Hz. The responses were evaluated according to the latency of the major negative peak N160 and inter-peak average amplitude in the positive–negative–positive complex.

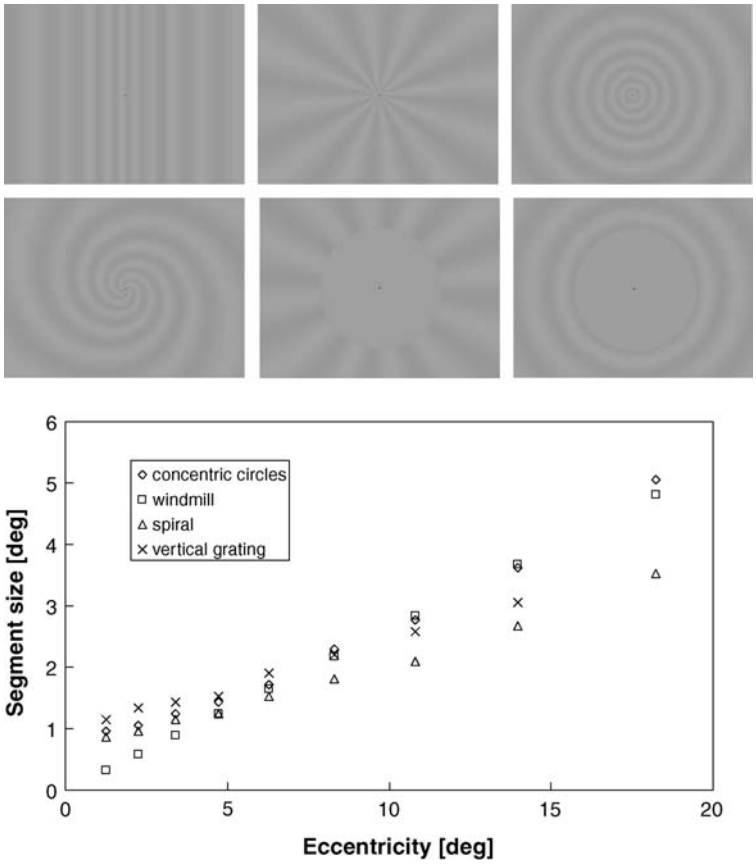

Figure 1. Hard copies of the stimuli are presented as they were seen during the stationary phase in following order: vertical grating (translating motion), windmill (rotation), concentric circles (radial motion), spiral (spiral motion), central 20° masked windmill (rotation) and central 20° masked circular pattern (radial motion). Segment size relation to the eccentricity for the basic patterns used in the experiments. The temporal frequency of 5.1 c/s was kept constant in the whole stimulus field.

Results

The maximal response for all subjects was recorded from the parieto-temporal region – over P3, PZ and P4 derivations. The scalp VEPs distribution to onset of the radial motion is depicted in the Figure 2 as a grand average with the standard derivation. A slight asymmetry of the maximum toward P4 was observed in one subject only, thus the PZ derivation was used for the M-VEPs evaluation. For the particular M-VEPs in all stimulus conditions see the Figure 3. Negative N160 peak dominated in all responses, in some subjects it was composed of two partially overlapping negative peaks [22,23]. In such a case, the later negative peak called N2b was evaluated as the N160. Average latency and amplitude values are listed in the Table 1.

MANOVA carried out on amplitudes and latencies showed that the effect of the different moving stimuli is significant ($F = 2.94$, $p < 0.003$). Then the paired t-tests were applied to verification of single latencies and amplitudes differences. Most distinct changes in latencies were found for translating motion and full-field rotation stimuli. The translating vertical grating evoked responses with significantly ($p < 0.05$) longer latencies compared to all other stimuli except the spiral motion. The full-field rotation on the other hand elicited significantly ($p < 0.05$) shorter latencies than any other stimuli. The radial, spiral motion and peripheral motions exhibited comparable latencies.

The amplitudes showed that translating motion evokes besides the longest latencies also significantly smaller amplitudes ($p < 0.05$)

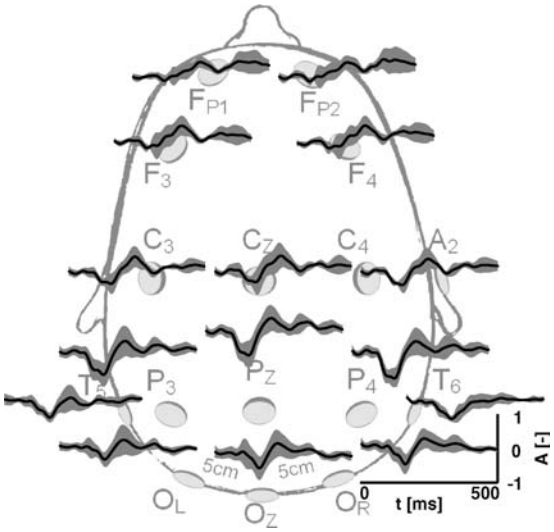

Figure 2. Scalp distribution of the M-VEPs to radial motion onset (expanding/contracting circular pattern). The grand-average, normalized in amplitude, M-VEPs with ±SD are plotted in a topological manner. The gray patch in background represents point-wise calculated ±SD of the grand-average.

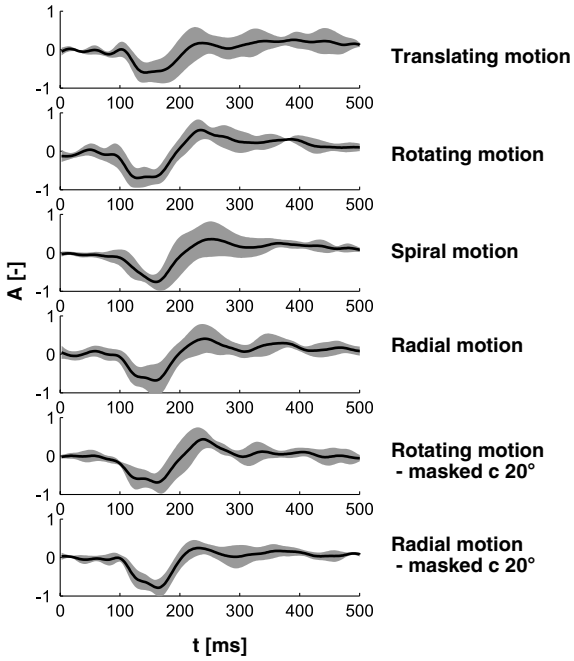

Figure 3. Comparison of the M-VEPs (grand-averages) to all tested stimuli from the PZ derivation in the group of five subjects (2F, 3M avg. 35 years <22–49>). The individual responses were normalized to equalize a contribution of one subject to the result. The point-wise calculated ±SD of the grand-average is plotted in the background.

compared to the radial motion (including the peripheral one) and the spiral motion. Also the 'rotation M-VEPs' had significantly smaller amplitudes ($p < 0.05$) compared to both full-field and peripheral 'radial motion M-VEPs'. In the radial motion M-VEPs there was no significant difference between the full-field and peripheral variant.

To asses a possible clinical use of examined stimuli, we compared ratio of the amplitude size to variability of the latency: $e = \text{avg(amplitude)}/\text{SD(latency)}$ [μV/ms]. The '*e*' coefficient reaches the highest value for responses with small variability and large amplitudes. Its superior value was achieved for the full-field radial motion followed by the peripheral radial motion and the spiral motion. The translating motion exhibited the lowest '*e*' value (for details see the Table 1 and the Figure 3).

Discussion

Among all stimuli, the longest latencies and the smallest amplitudes of the M-VEPs were found in translating motion. Compared to the other stimuli, this was the only unidirectional motion

Table 1. Descriptive parameters of the major negative motion-onset peak in different stimulation conditions expressed as mean ±SD

	Latency [ms]	Var. coeff. [%]	Amplitude [μV]	Var. coeff. [%]	*e* Amplitude/SD Lat. [μV/ms]
Radial motion	158.1 ± 6.0	3.8	14.2 ± 7.0	49.2	2.4
Translating motion	169.9 ± 17.1	10.1	9.2 ± 3.6	39.2	0.5
Spiral motion	159.0 ± 10.3	6.5	13.8 ± 5.5	39.6	1.3
Rotation	147.7 ± 11.0	7.5	10.1 ± 1.8	18.1	0.9
Masked radial m.	160.2 ± 8.8	5.5	14.1 ± 4.4	31.2	1.6
Masked rotation	158.3 ± 15.5	9.8	11.8 ± 3.5	29.2	0.8

and therefore, we can conclude that multiple directions stimulating simultaneously seem to be the important property for the dorsal stream activation (already reported from single unit studies of the primate MSTd area [24]). It is necessary to note that the translating stimulus structure contained spatial frequencies only along the horizontal abscissa. Despite the role of structure in the stimulus was suppressed (by low contrast and low spatial frequencies), it can not be omitted, since it was shown that even static patterns activate parts of the dorsal stream [25].

Another response differing from the others was the M-VEP elicited by rotation. Its significantly shorter latencies (compared to the other stimuli) disappeared when we masked the central 20° of the visual field. This implies that the central part was responsible for shorter latencies. When there is a distinct difference in spatial content of the windmill pattern in the central part (see Figure 1), then the presence of higher spatial frequencies in the macular area could be the reason of latency shortening. Nevertheless, this observation remains to be explored in more details.

The scalp distribution of the brain cortical responses to all stimuli exhibited maximum amplitude in the parieto-temporal region –see Figure 3, with grand average responses. It has to be noted that there is a difference in the location of the maximum N160 amplitude in this study compared to our previous papers. Formerly the motion-onset specific negative component N160 was mostly lateralized (irrespective to a dominance of hemispheres) into the temporo-occipital cortex [26]. The restricted number of derivations (unipolar OL, OZ, OR and bipolar OZ–CZ) used in that time might be one of reasons of the disproportion. This problem was recently addressed by Schellart et al. [23] with the use of MEG. They concluded that the motion specific component is likely generated bilaterally from areas V3/V3A and MT with overlapping effect on the scalp. Another explanation can arise from the different character of the stimulus, since even subjective perception of the radial and rotating motions is stronger compared to the translating motion that was used in the previous studies.

It should be pointed out that the presented responses are clearly covering a different part of visual information processing than the pattern-reversal VEPs examination explores (with the major response from the primary visual area [27]) and therefore, it is really reasonable to expect an increase of diagnostic sensitivity when pattern-reversal and motion-onset VEPs are combined.

The most promising stimulus for the motion-onset VEPs was the radial motion combining expansion–contraction (according to criterion based on amplitude magnitude and latency variability). The response to this stimulus did not exhibit significant differences in amplitude and latency of motion specific negative peak when central 20° is masked. Since for regularly used pattern-related VEPs there is a drop of amplitudes when stimulus is presented in periphery, e.g. the pattern-onset EPs can bring useful results only up to about 15° of eccentricity [28], we assume that the centrally masked expanding-contracting motion can produce larger responses and thus this type of motion-onset VEPs might serve as a simple objective test of peripheral vision.

Additionally, the proposed stimulus for the dorsal stream evokes simple shape of the VEPs, which allows identifying of the response even in severally affected system. The stimulus construction (low contrast and absence of high spatial frequencies) helps to minimize the initial positivity P1, presented mainly over the occipital striate area that might represent mainly a component related to pattern processing (pattern-disappearance effect at the beginning of motion) [26].

The needed timing of the motion stimuli (1 s ISI duration to prevent motion adaptation) does not prolong examination session too much since a sufficient signal-to-noise ratio is usually achieved already after 40 averaged sweeps. Further, the radial motion avoids optokinetic eye movements, what helps to correct visual fixation and can increase the quality of the signal.

The expanding/contracting stimulus gives the highest amplitudes among the explored motion stimuli in majority of subjects and it can be even stronger than the response to the pattern-reversal. An example of such recording is depicted in the Figure 4a, where the most distinct evoked response is the motion-onset VEPs to the radial stimulus demonstrating the stimulus strength in 33 years old female subject with suspected Multiple Sclerosis. The patient's response to pattern-reversal was very unreadable – many present peaks made the P100 detection difficult, therefore

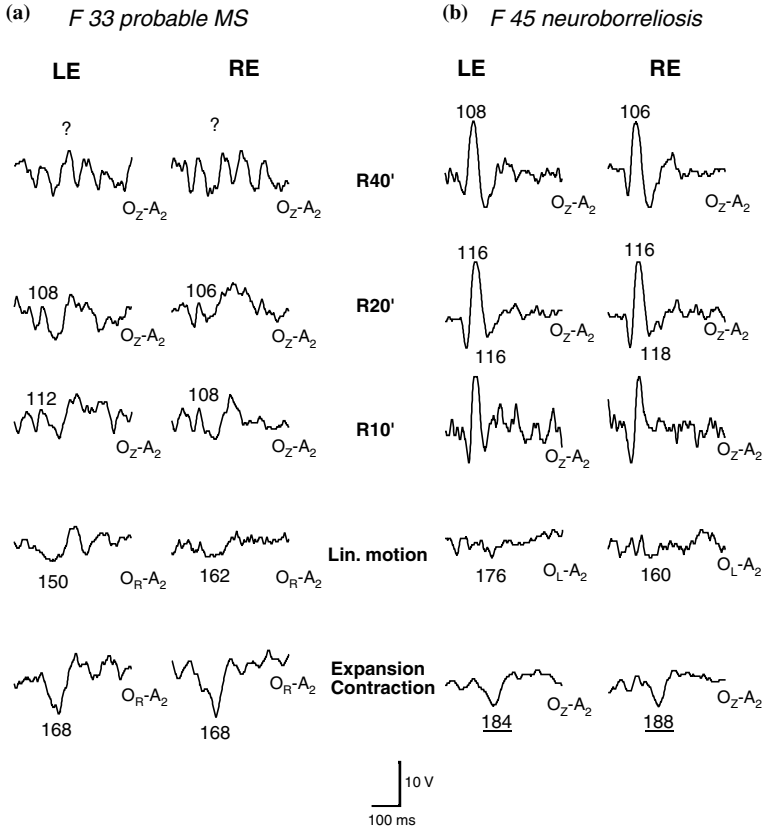

Figure 4. (a) The only enough prominent is the motion-onset response to the radial stimulus. It demonstrates the efficiency of the stimulus (the last row in the left half of the figure) and helps to a correct evaluation of the non-affected visual pathway function in 33 years old female with suspected Multiple Sclerosis. The pattern-reversal response from OZ derivation is drawn in the upper three rows (checkerboards 40, 20, 10 arc min., $L = 17$ cd·m^{-2}, $C = 99\%$, ISI = 500 ms). In the fourth row the motion-onset response to translating pattern of single checks ($L = 17$ cd·m^{-2}, $C = 10\%$, 200 ms motion duration, ISI = 500 ms) is plotted. The responses from left (LE) and right (RE) stimulated eye are displayed in the left and right columns. (b) Sensitivity of the Expansion–Contraction motion-onset VEPs stimulus is shown in the right part of the figure where prolonged latencies to this stimulus is the only pathology exhibited in 45 years female patient with Neuroborreliosis [the same arrangement of VEPs as in the (a) part].

the diagnostic decision based only on the pattern reversal VEPs could be very doubtful. However, complementary examination of the motion onset VEPs – especially by the radial motion having distinct response with normal latency brought very clear helpful information to the conclusion that the patient has intact optic nerve.

Application of sinusoid modulation of contrast in the radial pattern (decreasing amount of high spatial frequencies) forced the 'magnocellular character' of the used motion-onset VEPs. It further improved sensitivity of the motion-onset VEPs examination in some patients, mainly in a selective demyelination involvement of the magnocellular fibers of the optic nerve. The neuro-ophthalmological sensitivity and specificity of the new motion-VEPs will be evaluated in a separate paper, however, at least one example of beneficial use of the presented M-VEPs we demonstrate here – patient with Lyme's disease (Neuroborreliosis) is presented in the Figure 4b. When no other examinations (including MRI) exhibited any pathology, also pattern-reversal VEPs were fully normal, the M-VEPs to translating motion were not detectable enough, only M-VEPs to radial motion proved involvement of the visual pathway with significantly delayed latencies.

Acknowledgements

Supported by the Grant Agency of the Czech Republic (grant No. 309/02/1134) and by the

Czech Ministry of Education (CEZ: J13/98:111500001).

References

1. Kubová Z, Kuba M, Juran J, Blakemore C. Is the motion system relatively spared in amblyopia? Evidence from cortical evoked responses. Vision Res 1996; 36: 181–90.
2. Kubová Z, Kuba M, Spekreijse H, Blakemore C. Contrast dependence of motion-onset and pattern-reversal evoked potentials. Vision Res 1995; 35: 197–205.
3. Kubová Z, Kuba M. Clinical application of motion-onset visual evoked potentials. Doc Ophthalmol 1992; 81: 209–218.
4. MacKay DM, Rietveld WJ. Electroencephalogram potentials evoked by accelerated visual motion. 1968; 217: 677–8.
5. Clarke PGH. Visual evoked potentials to sudden reversal of the motion of a pattern. Brain Res 1972; 36: 453–458.
6. De Vries M, Van Dijk B, Spekreijse H. Motion-onset-offset VEPs in children. Electroenceph cl in Neurophysiol 1989; 74: 81–7.
7. Müller R, Göpfert E. The influence of grating contrast on the human cortical potential visually evoked by motion. Acta Neurobiol Exp 1988; 48: 239–49.
8. Göpfert E, Müller R, Simon E-M. The human motion onset VEP as a function of stimulation area for foveal and peripheral vision. Doc Ophthalmol 1990; 75: 165–173.
9. Kubová Z, Kuba M, Hubáček J, Vít F. Properties of visual evoked potentials to onset of movement on a television screen. Doc Ophthalmol 1990; 75: 67–72.
10. Schlykowa L, van Dijk BW, Ehrenstein W. Motion-onset visual evoked potentials as a function of retinal eccentricity in man. Cogn Brain Res 1993; 1: 169–174.
11. Bach M, Ullrich D. Motion adaptation governs the shape of motion-evoked cortical potentials. Vision Res 1994; 34: 1541–47.
12. Spileers W, Maes H, Orban GA. Visual evoked potentials to moving pattern stimuli. Electroencephalogr Clin Neuro 1996; 100: 287–98.
13. Odom JV, De Smedt E, Van Malderen L, Spileers W. Visually evoked potentials evoked by moving unidimensional noise stimuli: effects of contrast, spatial frequency, active electrode location, reference electrode location, and stimulus type. Doc Ophthalmol (1998–1999); 95: 315–33.
14. Bex PJ, Makous W. Radial motion looks faster. Vision Res 1997; 37: 3399–405.
15. Geesaman BJ, Qian N. A novel speed illusion involving expansion and rotation patterns. Vision Res 1996; 36: 3281–92.
16. Freemana TCA, Harrisa MG. Human sensitivity to expanding and rotating motion: effects of complementary masking and directional structure. Vision Res 1992; 32: 81–7.
17. Burr DC, Morrone MC, Vaina LM. Large receptive fields for optic flow detection in humans. Vision Res 1998; 38: 1731–43.
18. Holliday IE, Meese TS, Barnes GR. Evoked magnetic fields to optic flow stimuli are largest for expansion. Perception 1998; 27 (Suppl.): 17.
19. Heinrich SP, Bach M. Adaptation characteristics of steady-state motion visual evoked potentials. Clin Neurophysiol 2003; 114: 1359–66.
20. Koenderink JJ. Optic flow. Vision Res 1986; 26: 161–179.
21. Bach M, Ullrich D. Contrast dependency of motion-onset and pattern-reversal VEPs: interaction of stimulus type, recording site and response component. Vision Res 1997; 37: 1845–49.
22. Kremláček J, Kuba M, Kubová Z. Electrophysiological manifestation of first-order motion perception. Perception 1998; 27 (Suppl.): 192–3.
23. Schellart NA, Trindade MJ, Reits D, Verbunt JP, Spekreijse H. Temporal and spatial congruence of components of motion-onset evoked responses investigated by whole-head magneto-electroencephalography. Vision Res 2004; 44: 119–34.
24. Geesaman BJ, Andersen RA. The analysis of complex motion patterns by form/cue invariant MSTd neurons. J Neurosci 1996; 16: 4716–32.
25. Kourtzi Z, Bülthoff HH, Erb M, Grodd W. Object-selective responses in the human motion area MT/MST. Nat Neurosci 2002; 5: 17–8.
26. Kuba M, Kubová Z. Visual evoked potentials specific for motion-onset. Doc Ophthalmol 1992; 80: 83–9.
27. Shigeto H, Tobimatsu S, Yamamoto T, Kobayashi T, Kato M. Visual evoked cortical magnetic responses to checkerboard pattern reversal stimulation: a study on the neural generators of N75, P100 and N145. J Neurol Sci 1998; 156: 186–94.
28. Hoffmann MB, Straube S, Bach M. Pattern-onset stimulation boosts central multifocal VEP responses. J Vision 2003; 3: 432–9.

Address for correspondence: J. Kremláček, Charles University, Faculty of Medicine in Hradec Králové, Šimkova 870, 500 38 Hradec Králové, Czech Republic
Phone: +420-495 816 332; E-mail: jan.kremlacek@lfhk.cuni.cz