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Motion-onset VEPs: Characteristics, methods, and diagnostic use

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Abstract

This review article summarises the research on the motion-onset visual evoked potentials (VEPs) and important motion stimulus parameters which have been clarified. For activation of the visual motion processing system and evocation of the motion-onset specific N2 peak (with latency of 160–200 ms) from the extra-striate temporo-occipital and/or parietal cortex, the following stimulus parameters can be recently recommended: low luminance (<ca. 20 cd/m^2) and low contrast (<ca. 10%—sinusoidally modulated) of a moving structure with low velocity and temporal frequency (<ca. 6 Hz). A short (up to 200 ms) duration of motion and a long (at least 1 s) inter-stimulus interval reduce adaptation to motion and predominance of a pattern-related P1 peak. Radial motion (with increasing velocity and decreasing spatial frequency towards the periphery) produces larger reactions as compared to a unidirectional translation. In view of the slow maturation (up to the age of 18 years) and early ageing of the visual motion processing system, the use of age-dependent latency norms may be necessary. Since early or selective involvement of the motion processing system is suspected in some CNS disorders, we suggest an evaluation of the utility of motion-onset VEPs as part of the electrophysiological CNS examination since this method may recognise motion processing involvement better than other methods. Motion-onset VEPs might increase the sensitivity of this examination for diagnosing CNS diseases including Multiple Sclerosis, Neuroborreliosis, Glaucoma, Dyslexia and Encephalopathies.

Keywords: Visual evoked potentials; Motion-onset VEPs; Magnocellular system/dorsal stream; Visual motion stimuli; Radial motion; Clinical applications of motion-onset VEPs; Multiple Sclerosis; Glaucoma; Dyslexia

1. Introduction

Despite the relatively long history of visual evoked potentials (VEPs), their diagnostic use has so far been limited almost exclusively to flash or pattern (mainly pattern-reversal) related responses of the primary visual cortex (see IFCN standards—Celesia et al., 1993; ISCEV standards—Odom et al., 2004; Misulis & Head, 2003; Fahle & Bach, 2006) following the recommended stimulus conditions (high contrast and/or quite high spatial frequency), mainly via prevailing activation of the parvocellular system of the visual pathway (e.g., Livingstone, Rosen, Drislane, & Galaburda, 1991; Ellemberg, Hammarrenger, Lepore, Roy, & Guillemot, 2001). The requirement for standard VEP examinations for clinical diagnosis seems to be reduced since the introduction of new brain imaging techniques (mainly MRI), and the method is considered obsolete in some cases. Although VEP is a completely non-invasive, objective, and inexpensive investigation, which provides information about early functional changes of the visual pathway and visual brain cortex (which are sometimes recognisable prior to any detectable morphological changes observed by imaging techniques), it is surprising that efforts to extend it to more complex testing of visual and brain functions are quite rare.

An examination of the motion processing system (magnocellular system and dorsal stream) of the visual pathway is a necessary extension of VEP (Braddick, Atkinson, & Wattam-Bell, 2003). Some attempts to record various motion-related responses of the visual cortex were made

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many years ago (e.g., Clarke, 1973a, 1973b; Yokoyama, Matsunaga, Yonekura, & Shinzato, 1979; Gallichio & Andreassi, 1982; Göpfert, Müller, Markwardt, & Schlykowa, 1983; Spekreijse, Dagnelie, Maier, & Regan, 1985; Dagnelie, De Vries, Maier, & Spekreijse, 1986). However, these papers reported variable and controversial results which were not applicable to clinical diagnosis. Nevertheless, the majority of the important methodological factors which play a decisive role in the character of motion-related VEPs have been described, and some significant and promising diagnostic applications (mainly those which selectively involve the magnocellular system or the dorsal stream) have been developed.

However, the difficulty of generating the stimulation and the utilization of different recording and evaluation methods hampered the development of motion-related VEPs into routine neuro-ophthalmological diagnostics. Moreover, since the methods differ from those of a standard VEP examination, there is still doubt and scepticism about the reliability and diagnostic significance of motion related VEPs. In this article we try to summarise recent knowledge about the most commonly investigated type of motion related VEP, the *motion-onset VEP*, in an effort to promote the use of this method and to increase interest in the inclusion of an extended VEP examination in functional neuro-ophthalmological diagnostics. The clinical applications of motion-onset VEP that are described in this article are mainly based upon pilot studies from a few labs. Verification of their diagnostic value by evaluation of their specificity in clinical labs is suggested before their introduction into standard examinations.

2. Types of motion-related VEPs

Among all visual motion-related VEPs tested to date, *motion-onset VEPs* display the largest amplitudes and the lowest inter- and intra-subject variability (Göpfert et al., 1983; Kuba & Kubová, 1992; Kuba, Toyonaga, & Kubová, 1992; Bach & Ullrich, 1994; Skrandies, Jedynak, & Kleiser, 1998; Heinrich & Bach, 2003). Therefore, they seem to be the most promising modality for diagnostic purposes (e.g., Kubová & Kuba, 1992; Kubová & Kuba, 1995; Kubová, Kuba, Peregrin, & Nováková, 1995b; Kuba, Kremláček, Hůlek, Kubová, & Vít, 1996; Kubová, Kuba, Hrochová, & Svěrák, 1996b; Korth, Kohl, Martus, & Sembritzki, 2000). The much smaller amplitude of *motion-offset VEPs* require a longer duration of motion causing adaptation of the motion-processing visual cortex, which leads to inclusion of pattern related (most likely *pattern-on*) components (Clarke, 1973a, 1973b). To our knowledge, no diagnostic applications of *motion-offset* VEPs have been reported.

Motion-reversal VEPs represent responses to motion direction changes. They display large inter-subject variability of their shape (including also *pattern-on/off* components), which prevents clear identification of corresponding peaks (Kuba et al., 1992). The continuous motion stimulation, usually with changing directions in only one axis, causes motion adaptation and may provoke a dominance of pattern-related components (dependent on the temporal frequency and other parameters of a moving pattern—see below) (Odom, De Smedt, Van Malderen, & Spileers, 1999).

To date, *steady-state motion-related* VEPs using continuously moving stimuli have rarely been tested (e.g., Clarke, 1974; Tyler & Kaitz, 1977; Snowden, Ullrich, & Bach, 1995). Moreover, they do not seem to be a useful diagnostic variant of motion-related VEPs because of their variability (Heinrich & Bach, 2003).

So far, motion related VEP studies have used mostly *first-order* visual motion stimuli (defined by spatio-temporal luminance variations), although the V5 area (homologous to the area MT of the monkey) is also strongly activated by *second-order motion*, defined by differences in contrast or texture (Smith, Greenlee, Singh, Kraemer, & Hennig, 1998). However, the responses from *second-order* motion are dependent on a different neural mechanism with a slower response and higher variability (Ellemberg et al., 2003).

Chromatic moving stimuli have only been used rarely. It was reported that *motion-onset* responses have low chromatic sensitivity at higher motion velocities (>5 deg/s) (Mc Keefry, 2002).

With the use of a motion discrimination task also *motion event related potentials* (ERP—wave P300) can be recorded (Kuba, Kremláček, & Kubová, 1998; Kubová, Kremláček, Szanyi, Chlubnová, & Kuba, 2002).

Since this article is oriented toward the description of clinically useful motion-onset VEPs, it does not include many reports describing the theoretical physiological aspects of the motion-processing system.

3. Characteristics of motion-onset VEPs and their dependence on motion stimuli parameters

Motion-onset VEPs are typically composed of three main peaks—P1, N2 and P2. From Fig. 1 it is evident that there are basically two variants of the motion-onset VEP shape differing in their predominance of either a motion-specific N2 peak or pattern-specific P1 peak. The P2 peak rarely dominates and its increase is dependent on the recording site and type of motion (see below).

Although some early studies that used convenient stimulus parameters correctly reported (with respect to the current knowledge) the late *negative peak N2 with a latency of about 160–200 ms* as the *motion-onset specific component* (Yokoyama et al., 1979; Gallichio & Andreassi, 1982; Göpfert et al., 1983), the majority of the initial papers describing *motion-onset* VEPs (e.g., Clarke, 1973a, 1973b; Spekreijse et al., 1985; Dagnelie et al., 1986; De Vries, Van Dijk, & Spekreijse, 1989) concluded that the earlier positive peak P1 with a latency of about 130 ms represented the main *motion-onset* related potential. However, it is now evident that in these studies inadequate parameters of motion stimuli were used for the activation of the motion processing system.