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Aging effect in pattern, motion and cognitive visual evoked potentials

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ABSTRACT

An electrophysiological study on the effect of aging on the visual pathway and various levels of visual information processing (primary cortex, associate visual motion processing cortex and cognitive cortical areas) was performed. We examined visual evoked potentials (VEPs) to pattern-reversal, motion-onset (translation and radial motion) and visual stimuli with a cognitive task (cognitive VEPs – P300 wave) at luminance of 17 cd/m^2. The most significant age-related change in a group of 150 healthy volunteers (15–85 years of age) was the increase in the P300 wave latency (2 ms per 1 year of age). Delays of the motion-onset VEPs (0.47 ms/year in translation and 0.46 ms/year in radial motion) and the pattern-reversal VEPs (0.26 ms/year) and the reductions of their amplitudes with increasing subject age (primarily in P300) were also found to be significant. The amplitude of the motion-onset VEPs to radial motion remained the most constant parameter with increasing age. Age-related changes were stronger in males.

Our results indicate that cognitive VEPs, despite larger variability of their parameters, could be a useful criterion for an objective evaluation of the aging processes within the CNS. Possible differences in aging between the motion-processing system and the form-processing system within the visual pathway might be indicated by the more pronounced delay in the motion-onset VEPs and by their preserved size for radial motion (a biologically significant variant of motion) compared to the changes in pattern-reversal VEPs.

1. Introduction

There have been an increasing number of studies that have focused on identifying age-related visual impairments and their underlying mechanisms (for a review, see e.g. Owsley, 2010). Electrophysiological studies that have examined the aging of the visual pathway have been oriented so far mainly on the function of the form-processing system (parvocellular input to the primary visual cortex – e.g. Fiorentini et al., 1996; Mitchell, Howe, & Spencer, 1987; Porciatti et al., 1992; Zaletel et al., 2005). Such studies have used mostly pattern-related ("pattern-reversal") VEPs and reduction of their amplitudes and latency prolongation toward elderly were described. There are differences in the reported development of age related changes, probably due to various characteristics of the used stimuli. According to Page and Crognale (2005), the aging effect on the achromatic responses remains controversial because when compared to the chromatic pathway they did not found significant age-related changes.

Only few electrophysiological studies have tried to describe the aging processes within the motion-processing system (magnocellular pathway/dorsal stream). They used non-moving stimuli and were based on either pattern-reversal with low contrast and low spatial frequency (Gordon & McCulloch, 1999) or special flicker stimuli (Tomoda, Tobimatsu, & Mitsudome, 1999). To the best of our knowledge, the only electrophysiological study on the effect of aging using moving stimuli (motion-onset) was from our lab (Langrová et al., 2006). In this study, it was found that the maturation of the motion-processing system (reacting to the motion-onset of a low contrast pattern) lasted significantly longer (approximately up to 18 years of age), and the motion-processing system aged more rapidly compared to the form-processing system. It was repeatedly reported that with the use of low contrast motion stimuli (Kremláček, Kuba, Kubová et al., 2004) and proper motion timing (important is proportion between motion and non-motion periods – see Bach & Ullrich, 1994; Kuba & Kubová, 1992), the function of the visual motion-processing system can be quite selectively tested (e.g. Heinrich, 2007; Heinrich & Bach, 2003; Korth et al., 2000; Kuba & Kubová, 1992; Kubová et al., 1995; Kubová, Kuba, Juran et al., 1996; Kubová, Kuba, Peregrin et al., 1996; Kubová, Kuba, Hrochová et al., 1996; Schulte-Korne et al., 2004). The pattern-reversal VEPs (especially those to high contrast and high spatial frequency stimuli) seem to originate in the striate area (Brecelj et al., 1998; Di Russo et al., 2005) and it is considered that they represent predominant (not exclusive) activation of the form-processing system (parvocellular pathway/ventral stream – Bach & Ullrich, 1997). Although there are controversies about the extent of selectivity/specificity of these VEPs regarding the activation of the visual pathway subsystems, both

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types of VEPs should be complementary in visual system testing (for reviews, see Heinrich, 2007; Kuba et al., 2007).

In electrophysiological studies that examined the effect of aging in the visual cognitive processes, it has been shown that, despite a significant inter-individual difference in the latencies and amplitudes of the P300 wave of the cognitive evoked potentials, the P300 had a significant increase in its latency and a decrease in its amplitude with increasing age (Polich, 1996).

However, no electrophysiological study compared the age-related differences in various types of VEPs within the same group of subjects to verify the effect of aging on various levels of visual information processing. This comparison could help to recognize the most sensitive parts of the visual system and to further our understanding of various visual pathway disorders that occur in elderly subjects.

2. Methods

2.1. Subjects

The subjects consisted of 150 volunteers (81 females ranging from 15 to 83 years of age and 69 men ranging from 15 to 85 years of age) who did not suffer from any significant ophthalmological disorder (visual acuity was at least 0.5 in the better eye, as verified in our lab using the logarithmic Landolt "C" eye chart as administered by an experienced nurse) or reported a neuropsychiatric disease that could cause a deficit in visual perception and cognition. No subject was treated by any drug that could influence CNS functions. The electrophysiological examinations were performed in accordance with the Declaration of Helsinki, and our work fulfills the Uniform Requirements for Manuscripts Submitted to Biomedical Journals.

We attempted to study the widest age span possible. However, there were two limits. From our previous study (Langrová et al., 2006), we found that maturation of the motion-processing system and the age-related shortening of motion-onset VEP latencies continued for 18 years, and, therefore, inclusion of subjects from the age of 15 years could compromise the results. The second constraint was finding subjects with the required visual acuity and a good cooperation for ERP recordings (without signs of dementia as tested via Mini Mental State Examination) among seniors over 80 years of age.

The electrophysiological examinations occurred in all subjects at approximately the same time (10:00) and consisted of pattern and motion related visual evoked potentials (VEPs) and visually evoked cognitive-event related potentials (ERPs) that were recorded in a Faraday cage.

Recordings included unipolar derivations (with the right ear lobe reference) from the midline O_Z, P_Z, C_Z and F_Z and also from O_L and O_R (5 cm to the left and right from the O_Z position). The lateral recording sites were used because the N2 peak of M-VEPs was usually lateralized (irrespective of handedness of subjects due to different specialization of hemispheres to motion-perception) toward the temporo-occipital cortex (Kremláček, Kuba, Chlubnová et al., 2004; Kuba & Kubová, 1992). The non-uniform lateralization of reactions to motion-onset was also confirmed in MEG studies (e.g. Urakawa, Kaneoke, & Kakigi, 2011). Thus, only data from the derivation with the maximum response (i.e., with the largest amplitude) were analysed (O_Z in reversal VEPs, O_L, O_R or P_Z in M-VEPs and P_Z, C_Z or F_Z in ERPs) (Heinrich, 2007; Kuba et al., 2007).

Visual stimuli were generated using VSG 2.5 (CRS Ltd., UK) on a 21″ Iyama monitor (Japan) with a vertical frequency of 105 Hz. The stimulus field subtended 37 × 28 deg with a viewing distance of 0.5 m, and the average luminance was 17 cd/m^2. The correct fixation of the stimulus field center (fixation point) was monitored via infra-red CCD camera. All types of VEPs and ERPs were recorded at least twice, and the recording with the larger amplitude was used. Despite repeated attempts, some recordings did not provide trustworthy data. It means that the main peak (P100, N2 or P300) either was not present or it was ambiguous. Such recordings were eliminated from the evaluation. This elimination was necessary eight times (out of 150 subjects) in the motion-onset VEPs to translational motion. This could be because of inadequate stimulus parameters, which were kept constant, and, in some subjects, the motion stimuli require individual settings. It occurred once in P300 (possibly because of a different topography of a generator in the particular subject). Pattern-reversal and motion-onset VEPs to radial motion (representing a variant of notably robust, biologically important stimulus, named "optic flow", as described below) were recorded successfully in all 150 subjects.

2.2. VEPs and ERPs acquisition and evaluation

Two types of visual stimuli (pattern-reversal and motion-onset) and visual cognitive tasks were used to test the function of the visual pathway and its cortical projections in a complex way.

(1) In the *pattern-reversal stimulation*, a black/white checkerboard with element sizes of 20′ (with 96% contrast according to Michelson) was reversed at a frequency of 2 rev/s.
(2) For acquisition of the motion-onset VEPs (M-VEPs), two variants of the moving stimuli were used:
   (a) *Translating (unidirectional linear) motion* of low contrast (10%) isolated checks (40′ check size and 120′ check-to-check distances). The pattern moved pseudo-randomly in one of four fundamental directions with a velocity of 10 deg/s.
   (b) *Radial motion* was randomly performed in centrifugal or centripetal motion ("expansion/contraction") in low contrast (10%) concentric circles with sinusoidal luminance modulation. The structure of the spatial frequency decreased, and the motion velocity increased from the center (fixation point) towards the periphery with respect to the size of the retinal receptive fields and the sensitivity to motion velocity across the retina (Kremláček, Kuba, Kubová et al., 2004).

When the structure was stationary, both moving stimuli had the same timing of 200 ms of motion, which was followed by 1 s interstimulus interval.

In the pattern-reversal and motion-onset VEPs, the subjects were stimulated monocularly. We examined the eye with better visual acuity, which was at least 0.5 with eventual correction, or the dominant eye when both eyes had an identical VA. Examination of only one eye allowed us to include subjects with one-sided visual problems. This approach also shortened the time of the whole examination, which was important mainly for older patients who became inattentive and it could change the parameters of the VEPs (Kremláček et al., 2007). For all VEPs, 40 single responses were averaged at 440 ms epochs with a sampling frequency of 500 Hz. In the *pattern-reversal VEPs*, we measured the peak latencies and the inter-peak mean amplitudes ($(A_1 + A_2)/2$; A_1 = N75-P100 inter-peak amplitude, A_2 = P100-N135 inter-peak amplitude) of the main P100 peak, and, in the M-VEPs peak latencies and inter-peak mean amplitudes of the N2 peak, this peak was shown to represent the main motion related component of this VEP type (for review, see Heinrich, 2007; Kuba et al., 2007).

2.3. ERPs acquisition and evaluation

Binocular ERPs were recorded during an oddball test where the white letter X (frequent, non-target stimulus with a probability of 75%) and Arabic digits 1–9 (rare, target stimulus with a probability

of 25%) at 5.7 × 6.3 deg were placed in the center of the black stimulus field (with an average luminance of 1 cd/m^2) appeared pseudo-randomly. The "X" or the digit was displayed for 500 ms, which was followed by 500 ms of a blank screen with the fixation point. The subjects were instructed to mentally count the sum of the digits appearing in the target stimuli that were checked at the end of stimulation to keep their attention and motivation. For the ERPs, 20 epochs to the target stimuli and 20 randomly selected epochs to the non-target stimuli (both with a 1000 ms duration and a sampling frequency of 250 Hz) were averaged for each condition. Before averaging, the epochs with artifacts (e.g., eye blinks) were manually rejected.

We used the same procedure for ERPs acquisition (including the "target"/"non-target" stimuli proportion) as in previous studies (Kubová et al., 2005, 2010) that provided a sufficient signal-to-noise ratio and a significant P300 amplitude in the "target" responses. This experimental design represents a compromise between an optimal stimulus procedure for maximal ERPs (amplitude) and a short duration of the study, which was necessary to maintain the stability of the reactions during the whole examination.

In the ERPs, for frequent and rare stimuli, the inter-peak amplitudes and the peak latencies of the P300 (P3b, Polich, 2007) were measured.

Schemes of all stimuli are presented in Fig. 1, and the stimuli are also demonstrated on our lab's webpage http://www.lfhk.cuni.cz/ELF/.

2.4. Statistics

To assess the effects of aging, we evaluated the correlations between the age of the subjects and the VEPs/ERPs characteristics and parameters of their regression lines for the whole group and separately for males and females. Non-parametric statistics were used because of the non-Gaussian distribution of the electrophysiological data – medians and percentiles as basic statistical descriptors, Spearman's rank correlation coefficients for correlation analysis (Matlab-function "Corr") and univariate test of slope homogeneity – general linear model (Statistica 9.1) for evaluation of gender differences in regression.

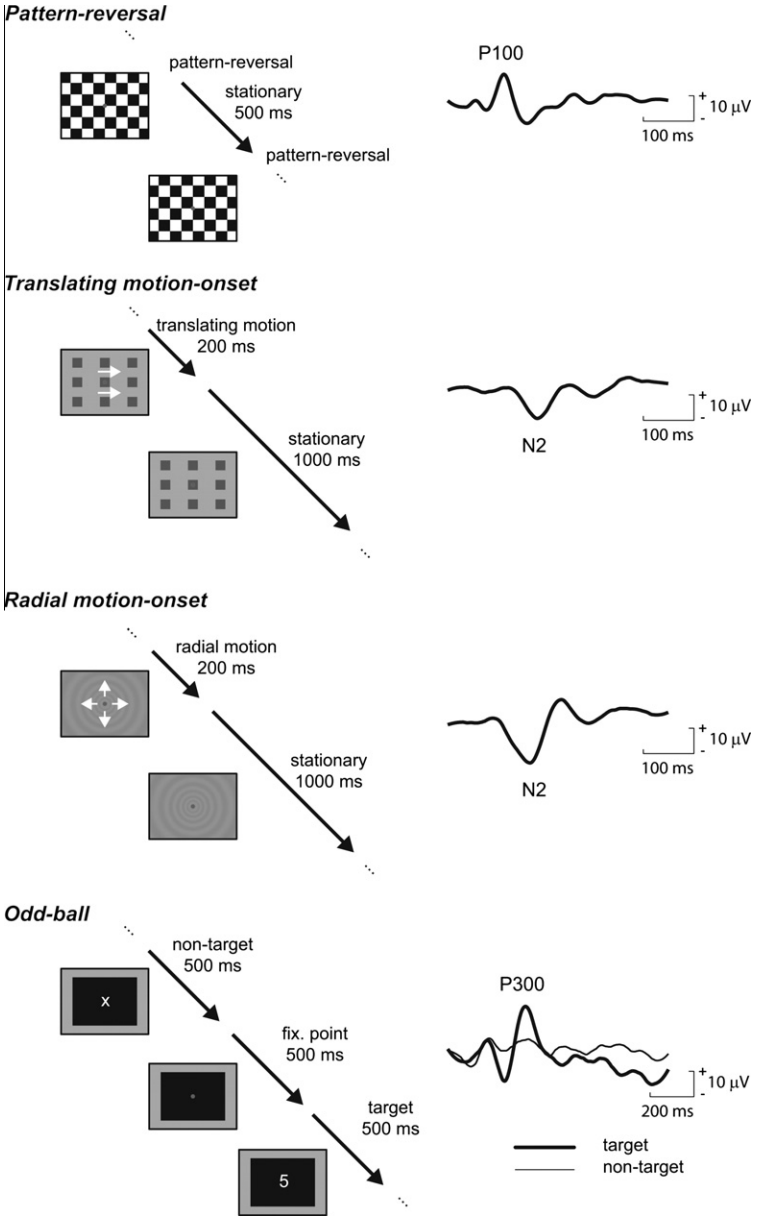

Fig. 1. Schemes of all stimuli for VEPs and P300 registration.

Table 1
Basic statistical data.

		n	Median	Minimum	Maximum	25th percentile	75th percentile
Whole group							
Age	(years)	150	33.5	15.0	85.0	22.0	50.0
P300	lat (ms)	149	388.0	312.0	580.0	368.0	425.0
P100	lat (ms)	150	114.0	98.0	142.0	108.0	119.0
N2 trans	lat (ms)	142	168.0	134.0	220.0	160.0	182.0
N2 rad	lat (ms)	150	166.0	130.0	216.0	156.0	178.0
P300	ampl (μV)	149	14.9	3.3	35.1	11.0	19.6
P100	ampl (μV)	150	11.1	1.7	28.8	7.5	14.6
N2 trans	ampl (μV)	142	6.1	1.1	17.6	4.8	8.3
N2 rad	ampl (μV)	150	10.2	3.8	22.6	8.0	12.7
Females							
Age	(years)	81	34.0	15.0	83.0	22.0	47.0
P300	lat (ms)	81	388.0	336.0	504.0	368.0	417.0
P100	lat (ms)	81	112.0	98.0	142.0	108.0	118.0
N2 trans	lat (ms)	77	168.0	141.0	218.0	157.8	182.0
N2 rad	lat (ms)	81	166.0	130.0	216.0	156.0	176.0
P300	ampl (μV)	81	14.5	3.3	35.1	11.5	19.1
P100	ampl (μV)	81	12.8	3.2	28.8	9.2	15.7
N2 trans	ampl (μV)	77	6.2	1.1	17.6	4.9	8.8
N2 rad	ampl (μV)	81	10.4	3.8	22.6	8.0	14.2
Males							
Age	(years)	69	32.0	15.0	85.0	23.0	57.0
P300	lat (ms)	68	390.0	312.0	580.0	370.0	440.0
P100	lat (ms)	69	116.0	98.0	140.0	110.0	120.0
N2 trans	lat (ms)	65	170.0	134.0	220.0	160.8	180.5
N2 rad	lat (ms)	69	166.0	133.0	210.0	152.5	178.5
P300	ampl (μV)	68	15.3	4.6	34.4	9.7	19.6
P100	ampl (μV)	69	9.4	1.7	23.0	6.2	12.3
N2 trans	ampl (μV)	65	6.0	1.6	16.1	4.7	8.0
N2 rad	ampl (μV)	69	9.6	4.2	16.8	8.2	11.7

Evaluated parameters are provided for all subjects and separately for males and females. Because of the non-Gaussian distribution of data, the description is based on the median and percentile values.
lat = latency; ampl = amplitude.
N2 trans = N2 peak in motion-onset VEPs to translation motion.
N2 rad = N2 peak in motion-onset VEPs to translation motion.

3. Results

Basic statistical data of the parameters for all subjects and male and female subgroups are summarized in Table 1. Individual values of the latencies and amplitudes and their dependence on the age of the subjects in all recorded potentials are displayed in scatter diagrams in Fig. 2.

Table 2 provides descriptors of the regression curves of the VEP parameters that displayed a significant correlation with age (the amplitude of the motion-onset VEPs to radial motion was not included due to its non-significant correlation with age).

3.1. Latency changes (Table 2)

All variants of the VEPs have a significant delay in elderly subjects, which was more pronounced in the visual P300. This prolonged latency was linearly dependent on the age (in the tested age span) for all VEPs and P300. The dependence was highest in P300 despite the larger inter-individual variability (coef. of determination $R^2 = 0.601$; $p < 0.001$). The delay was 2.01 ms per year of age compared to the relatively small delay of 0.26 ms per year in the pattern-reversal VEPs, which was also significant, due to the low inter-individual variability. The prolongation of the N2 peak latency in the motion-onset VEPs with increasing age was similar for the reactions to the translation (0.47 ms/year) and radial motion (0.46 ms/year).

3.2. Amplitude changes (Table 2)

In the group of all subjects the amplitudes of the recorded evoked potentials were linearly reduced with increasing age (mostly in P300; $R^2 = 0.263$; $p < 0.001$) with the exception of the N2 peak amplitude in the reactions to the radial motion onset where the size remained constant throughout all ages tested. However, in the subgroups of females and males the trend of the other amplitudes (with exception of P300) to reduce toward elderly is non-significant.

The grand averages for the eight age groups in Fig. 3 shows age related changes in the original VEP and ERP recordings.

3.3. Gender differences (Table 2)

Deterioration of the electrophysiological parameters, particularly the increased latency, in the elderly subjects was stronger in males than in females (see Table 2). The largest difference was in the P300 latency of ERPs. This latency was prolonged for 2.3 ms per year in men and for 1.6 ms per year in women (coef. of determination $R^2 = 0.676$ resp. 0.515). The effect of sex as a categorical predictor was tested using a univariate test of slope homogeneity (general linear model, Statistica 9.1). The interaction between sex and age was significant for the P300 latency ($p = 0.011$) and P100 latency ($p = 0.027$). The formulas of regression models for females were:

$$\begin{aligned}\text{P300 lat} &= 339.3 + 1.53 * \text{Age [ms] and P100 lat}\\ &= 101.9 + 0.32 * \text{Age [ms]; for males, the formulas were}\\ &: \text{P300 lat} = 316.2 + 2.32 * \text{Age [ms] and P100 lat}\\ &= 99.6 + 0.45 * \text{Age [ms]}.\end{aligned}$$

Although males aged more rapidly, based on the model for P300 latency, at younger ages they can have shorter latencies relative to women.

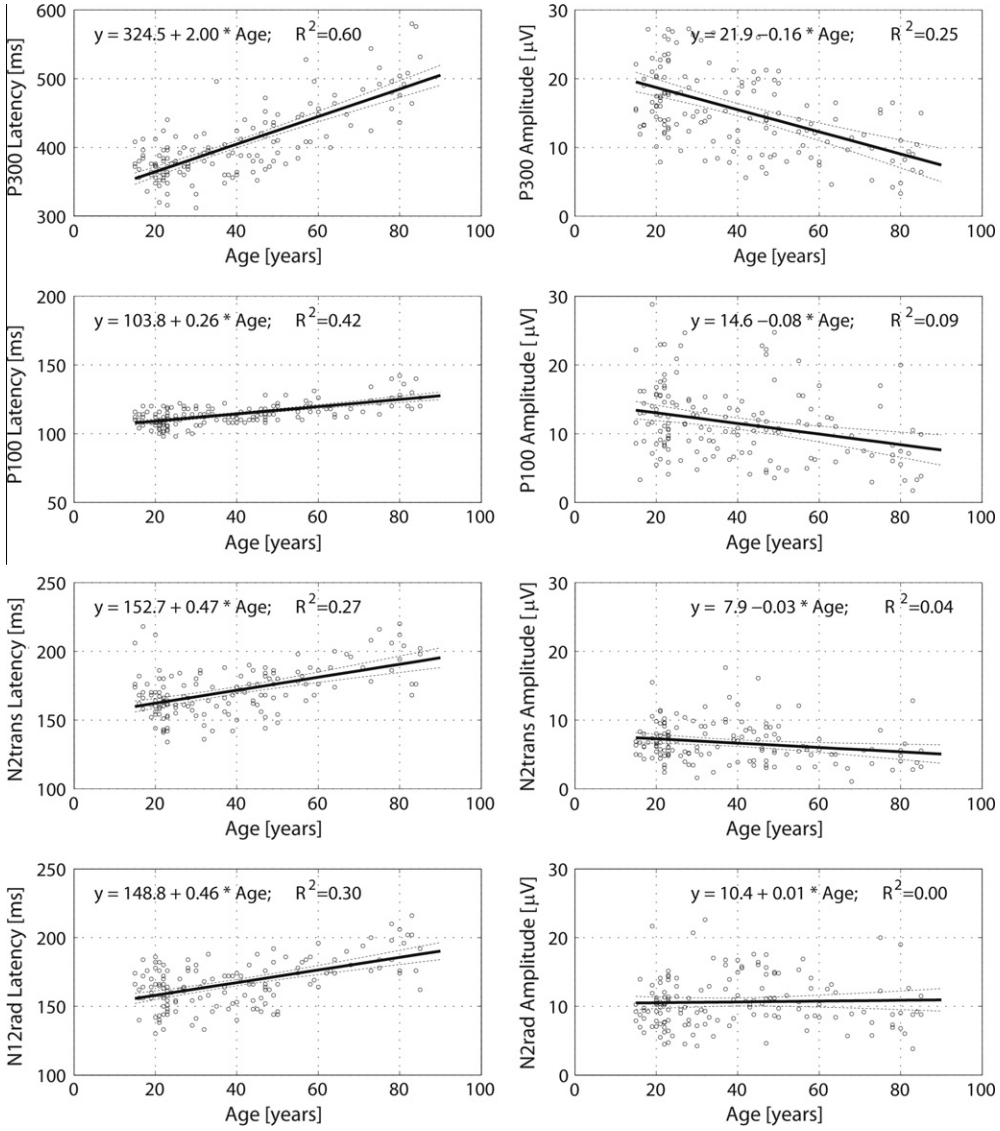

Fig. 2. Scatter diagram of the latencies and amplitudes of VEPs and P300 for all subjects. Regression lines are plotted with 95% confidence ranges, regression line formulas and coefficients of determination are assigned.

4. Discussion and conclusions

In this study, we have described electrophysiological parameters related to visual information processing from the level of primary cortical visual areas via the secondary extrastriate motion processing visual cortex to the cognitive processes in the centro-parietal and frontal brain cortex in a large group of 15-to-85-year-old subjects. Based on these data (VEPs and P300 latencies and amplitudes), we compared the progression of age-related changes in the function of different parts/systems of the visual pathway and visual and cognitive cortical areas. The extent of such changes was evaluated according to the significance of the correlation coefficients between the electrophysiological parameters and the age of the subjects and also according to the "slope" of the curves, which represent the linear dependencies of these parameters on age (Tables 1 and 2 and Fig. 2). Because the significance of correlation was dependent on the variability of the data (which is different in various parameters), the "slope" ("*b*" parameter in the formula of the regression line) was more informative about the extent/promptness of the age-related changes.

To our knowledge, this is the first electrophysiological study that simultaneously evaluated the effects of aging on three different levels of visual information processing (in the same group of subjects). Although we cannot argue that there is a direct relationship between the tested parameters and the age-related functional changes of the visual system, our results suggest some new information.

Because the most significant changes with increasing age were the increased latency and the reduction of the amplitude of the ERP-P300 wave, the cognitive processes were more influenced by the aging processes compared to the lower levels of the visual system. Thus, despite the larger variability, the P300 parameters represent the most sensitive electrophysiological indicator of aging in visual information processing. Several studies have reported significant changes of P300 with aging (for review see Polich, 1996) and its deterioration, e.g., in Alzheimer's disease (Kavcic, Vaughn, & Duffy, 2011; Kubová et al., 2010); however, this study, with parallel testing of several visual processes, suggests that the P300 changes represent the dominant age-related change, which seems to be independent on lower-level involvement of the visual pathway.

Table 2
Descriptors of regression lines in significant correlations with age.

		Intercept [CI]	Slope [CI]	R^2 (–)	Spear *R*	*p* <
Whole group						
P300	lat (ms)	324.5 [312.9 336.2]	2.005 [1.738 2.271]	0.601	0.674	0.001
P100	lat (ms)	103.8 [101.6 106.1]	0.263 [0.213 0.314]	0.417	0.569	0.001
N2 trans	lat (ms)	152.7 [147.1 158.4]	0.473 [0.342 0.603]	0.268	0.425	0.001
N2 rad	lat (ms)	148.8 [143.8 153.9]	0.460 [0.345 0.574]	0.298	0.416	0.001
P300	ampl (μV)	21.9 [19.9 23.9]	−0.161 [−0.206–0.116]	0.255	−0.483	0.001
P100	ampl (μV)	14.6 [12.8 16.4]	−0.077 [−0.118–0.037]	0.088	−0.304	0.001
N2 trans	ampl (μV)	7.9 [6.8 9.0]	−0.032 [−0.056–0.007]	0.044	−0.225	0.010
N2 rad	ampl (μV)	–	–	–	–	–
Females						
P300	lat (ms)	336.9 [322.3 351.6]	1.600 [1.252 1.947]	0.515	0.606	0.001
P100	lat (ms)	103.5 [100.2 106.8]	0.256 [0.177 0.335]	0.346	0.444	0.001
N2 trans	lat (ms)	152.0 [143.6 160.3]	0.497 [0.297 0.697]	0.247	0.394	0.001
N2 rad	lat (ms)	152.3 [145.2 159.3]	0.370 [0.202 0.538]	0.195	0.315	0.010
P300	ampl (μV)	22.3 [19.5 25.1]	−0.175 [−0.241–0.109]	0.263	−0.506	0.001
P100	ampl (μV)	16.0 [13.3 18.6]	−0.075 [−0.138–0.012]	0.066	−0.300	0.010
N2 trans	ampl (μV)	–	–	–	–	–
N2 rad	ampl (μV)	–	–	–	–	–
Males						
P300	lat (ms)	314.7 [296.6 332.8]	2.336 [1.939 2.733]	0.676	0.747	0.001
P100	lat (ms)	104.5 [101.5 107.6]	0.264 [0.198 0.331]	0.487	0.698	0.001
N2 trans	lat (ms)	153.3 [145.5 161.2]	0.452 [0.277 0.626]	0.297	0.465	0.001
N2 rad	lat (ms)	145.8 [138.4 153.3]	0.533 [0.372 0.693]	0.395	0.497	0.001
P300	ampl (μV)	21.7 [18.7 24.7]	−0.151 [−0.215–0.087]	0.250	−0.460	0.001
P100	ampl (μV)	–	–	–	–	–
N2 trans	ampl (μV)	–	–	–	–	–
N2 rad	ampl (μV)	–	–	–	–	–

Correlation significance was corrected for multiple comparisons. Each parameter estimate is followed by its 95% confidence interval. The goodness of fit is expressed by the coefficient of determination R^2. Parameters of amplitude regression models are not included in the case of a non-significant correlation to the subject's age.
Intercept – parameter "*a*" of regression line.
Slope – parameter "*b*" of regression line.
R^2 – coefficient of determination.
Spear *R* – Spearman's rank correlation coefficient.
p – *p*-value of the test for correlation significance.

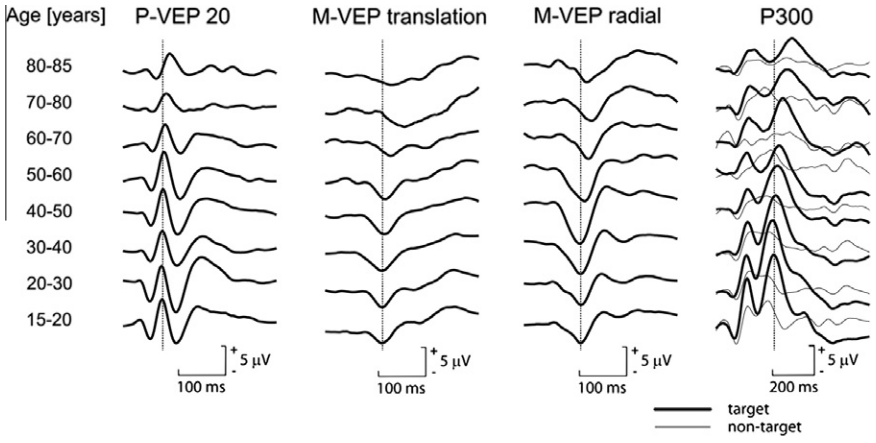

Fig. 3. Grand averages in eight age subgroups for all VEPs and P300. Vertical lines denote latencies in the youngest age group to simplify visual inspection of the latency changes associated with increasing age.

Although the correlation between age and pattern-reversal VEP peak latencies was the second most significant, it was caused primarily by a low variability of the P100 peak, and the age-related increase of this parameter was relatively small (0.26 ms/1 year). Age-related norms in the evaluation of this parameter for diagnostic purposes are not commonly used. In agreement with report by Langrová et al. (2006), more important is the latency prolongation of the N2 peak in both variants of motion-onset VEPs, which was approximately 0.5 ms/year. Therefore, the age-related norms for the motion-onset VEP latencies seem to be necessary.

Our evaluation of age related changes in visual information processing was based on evaluation of dominant VEP peaks only. Although it is a common way of VEP assessment related to visual functions (e.g. Martin et al., 2010), a more precise testing of these processes is possible via complex analysis of "multiple post-stimulus time points" (e.g. Rousselet et al., 2010).

Interestingly, the reactions to the radial motion onset did not reduce their size (amplitudes) during aging despite the significant increase in the latency. This finding is consistent with the previous study that showed the same independence of this amplitude on age (Langrová et al., 2006). Thus, we can speculate that this characteristic might be related to a special biological mechanism of the radial motion (expansion/contraction of a structure) in our sensation (Holliday, Meese, & Barnes, 1998). Radial motion

represents an "optic flow", the apparent motion of objects in a visual scene that is perceived while moving through the world. In such a case, the constant size of these potentials could indicate a selective protection of important percepts during aging of the CNS.

It is remarkable that the amplitude reduction of the reactions to radial motion (especially by stimulation outside the central 20° of the visual field) was the only significant VEP difference found among a group of patients with Alzheimer's disease and age-matched control subjects (Kubová et al., 2010). Thus, we can assume that the amplitude reduction of the VEP reflects a special problem in the central processing of visual motion information, while conductivity of the visual pathway undergoes the normal aging process in Alzheimer's disease.

It is notable that a delay of the reaction to the radial motion onset was significant in a subgroup of dyslexics in whom a magnocellular system/dorsal stream deficit is suspected (Kuba et al., 2001).

The discrepancy between the increase in the latency and stable amplitudes of the motion-onset VEPs (radial motion) in normal aging might reflect unrelated changes in conductivity and maintained cortical processing of important information. The systematic increase of the motion-onset VEP latencies beginning in early adulthood may be a good indicator of individual biological aging. It might be dependent on the supposed higher sensitivity of the motion-processing pathway (neurons) and the association of cortical areas to possible degenerative processes due to speculated ischemic, toxic or peroxidation factors (Kilic, 2003).

The suggested difference observed in motion-onset VEPs to translational and radial motion could be consistent with reports about the separate processing of these motions in MT and MST cortical areas (Vaina, 1998) and with our findings of a different diagnostic value of motion-onset VEPs to translational and radial motion in some diseases (for review see Kuba et al., 2007).

We should mention that possibly a lower retinal illumination (caused by senile miosis) could contribute to the VEP latency increase (for review see Rousselet et al., 2010), and thus a higher luminance for testing might seem to be preferable. We used a relatively low luminance (17 cd/m^2) because we have an experience from our clinical studies that in the lower luminance some pathologies are better detectable in VEP examinations. If the used low luminance has influenced our results in old subjects, it would mainly prolong P100 latencies (the most sensitive parameter to luminance changes). But just on the contrary, N2 of the motion-onset VEPs were more delayed in old subjects, although N2 peak is quite insensitive to luminance (Kubová et al., 2004).

We believe that this study has contributed to the idea that visual electrophysiology might be useful in objectively testing the CNS aging processes that influence visual perception and cognition. This finding suggests that a more complex electrophysiological examination at several levels of visual information processing could differentiate normal and pathological aging processes.

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