Eötvös Loránd University, Faculty of Education and Psychology

Age-related psychophysiological changes of cognitive processes

Doctoral theses

Zsófia Anna Gaál

Tutor: Dr. Márk Molnár, DSc

Doctoral School in Psychology
Head of School: Dr. György Hunyady, DSc

Doctoral Programme in Cognitive Psychology
Head of Programme: Dr. István Czigler, DSc

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1. Introduction

Aging effects are studied in this paper by EEG recorded in simple cognitive tasks. Resting EEG and its frequency bands, event-related potentials (ERPs: N1, P2, N2, P3b, P3a, CNV) in auditory and visual tasks are discussed.

Both the microscopic and macroscopic structure and the function of the central nervous system change during the ontogenesis. The most affected area of all in this process is the frontal cortex.

The cognitive theories of aging are based on behavioural data and do not discuss the changes of brain activation. Nevertheless, the results of psychophysiological studies can be adjusted to these theories. The main theories, which are not mutually exclusive, in this area: the sensory deficit theory, the speed deficit theory, the resources deficit theory, the inhibition deficit theory and the frontal / executive control deficit theory.

Aging effects can be observed already in the resting EEG. During the first two decades these can be related to the maturation of the brain. The amplitude of the EEG is smaller, delta and theta activities are decreased, alpha activity is increased. Relative alpha power and frequency reach their peak at 25 years and then decrease after the age of 30, while the relative theta power shows the opposite pattern. An age-related monotonous increase can be seen in relative beta power.

Alpha frequency slows down, its amplitude decreases and the maximum moves to anterior sites with aging. Coherency between the two hemispheres is decreased, EEG complexity is increased in elderly adults.

It is well known that aging has an influence on the ERP components, but the question to what extent the different components are affected, and what mechanisms could be behind these processes is not yet clear.

Most of the papers claim that the latency of the N1 component does not change with aging, but some authors have found a moderate increase. The results connected with the N1 amplitude are also diversed. A frontocentral increase was found in some cases, while others could not demonstrate any age-related changes. Most of the papers have not reported changes in P2 latency with aging, but in some an increase was reported. The amplitude of the P2 component was found to be either increased or decreased, or not changed at all.

The latency of the N2 component shows a linear increase with aging, but the data concerning its amplitude are inconsistent.

The latency of the P3b component increases with aging. Most papers found a linear increase, some reported acceleration from the age of 45 years. P3b amplitude does not change with aging, or if a change can be found, it is mostly a decrease. Age-related change of the P3b distribution is also typical: it can be seen with a parietal maximum in young adults, while the elderly adults it has a frontal peak also.

CNV studies comparing young and older participants reported that CNV amplitudes were similar or smaller in the elderly relative to young adults. The absence of age effect can be due to motor preparation when a motor response is necessary.

The structural and functional changes with aging also influence the processing of emotional stimuli. Experiments in this field use complex affective pictures or faces. The results show that the subjective experience of elderly adults is enhanced compared to young subjects, while their physiological reactivity is decreased. According to a recent approach, elderly adults show a positivity bias. The cause of the differences can be that the different age groups use different neuronal circuits during perception and processing of emotional stimuli.

2. Experiments

We examined first whether group differences could already be seen during the resting state and how did the age groups react to the activation caused by opening of the eyes.

After this, the results obtained during auditory oddball paradigms were analyzed, during which the effects of task difficulty and instruction were examined in five age-groups.

The novelty oddball paradigm, during which the complexity of the task was increased owing to the novel stimuli, was also studied parallel to the two-tone oddball task. These tasks (among others) engage attention and memory systems that are the new factors during the analysis of age differences.

The fourth experiment goes beyond on a simple visual oddball task in that the stimuli were complex emotional pictures; the new parameter studied was emotion.

The last condition shows how emotional stimuli influence the execution of a CNV task (which demands more permanent attention) in young and elderly adults.

3. Method

3.1. Participants

1st experiment: 64 participants were divided into 2 groups: young (18-35 yrs, n=31 – 16 women, 15 men, mean age: 22.71±3.58 yrs), and elderly adults (60-75 yrs, n=33 – 26 women, 7 men, mean age: 66.09±3.88 yrs).

2nd and 3rd experiment: 55 persons participated in this study (39 women and 16 men). The following 5 age groups were defined: (I) 18-29 yrs (mean age: 24.5±3.1 yrs, n=12), (II) 30-39 yrs (mean age: 33.2±2.6 yrs, n=12), (III) 40-49 yrs (mean age: 43.1±3.1 yrs, n=9), (IV) 50-59 yrs (mean age: 53.8±2.2 yrs, n=11), (V) 60-70 yrs (mean age: 63.7±2.1 yrs, n=11).

4th experiment: 20 young (21.75 ± 1.65 yrs, 8 women, 12 men) and 20 elderly (66.65 ± 4.11 yrs, 13 women, 7 men) adults participated in this experiment.

5th experiment: Two groups were defined: young adults (n=17, 7 women and 10 men) were 18-23 yrs old (mean age: 20.7±2.02 yrs), elderly adults (n=16, 13 women and 3 men) were 62-75 yrs old (mean age: 66.7±3.93 yrs).

3.2. EEG recording

The EEG was recorded by NuAmp amplifiers (bandpass: DC-40 Hz or DC-70 Hz) using NeuroScan 4.3 software (sampling rate: 1000 Hz) by Ag/AgCl electrodes (19 or 33) referred to the tip of the nose, with forehead or FCz as ground. Vertical and horizontal eye movements were also recorded.

4. Recording paradigms and results

4.1. Resting EEG

Two-minute EEG-recordings were performed both in eyes closed and eyes open conditions. Frequency differences were studied between the age groups ("slowing" of the EEG). We hypothesized that reactivity to eyes opening was lower in elderly persons shown by absolute spectra and complexity changes. We also hypothesized that increased Omega complexity and decreased synchronization likelihood could be found in the older group, occurring mainly in the frontal areas, corresponding to the frontal theory of aging.

4.1.1. Results

Frequency bands showed no differences between age groups, but the total power did. Opening the eyes caused power decrease in young adults not seen in the elderly, which indicates a decrease in reactivity with aging. Area differences between the two groups were detected above posterior sites based on the spectrum analysis.

Omega complexity increased, synchronization likelihood decreased to eyes opening in the 4-40 Hz frequency band. Omega complexity showed group differences during the eyes open condition: it was higher in elderly people. Omega complexity was also higher in the anterior sites compared to the posterior areas, and its value was higher in elderly compared to the young adults at anterior sites. Synchronization likelihood also showed age-related differences: it was higher in the young group at anterior sites compared to the elderly subjects.

While the spectrum analysis did not show the manifestation of the supposedly existing structural changes with aging, complexity analysis indicated the age-related sensitivity of the anterior areas. The results refer to the decline of interneuronal connectivity and effectiveness of information processing.

4.2. Auditory oddball paradigms

Age-related ERP changes were studied in auditory oddball paradigms. It was hypothesized that the later the component is, the greater the aging effect will be, as manifested by its latency, amplitude and distribution.

Two-tone and novelty oddball tasks were used. Two-tone oddball paradigm was performed with two difficulty levels: easy (standard tone: 1000 Hz, probability: 0.8, target tone: 1100 Hz, 0.2 probability) and difficult (standard tone: 1000 Hz, 0.8 probability, target tone: 1050 Hz, probability: 0.2). In subsequent sessions two kinds of instructions were given. Subjects were asked either to be accurate or fast when making a response.

In the novelty oddball paradigm 1000 Hz (standard), 1500 Hz (target) tones and "novel" (complex environmental sounds without repetition) stimuli (probability: 0.85, 0.1 and 0.05, respectively) were presented with 1 s ISI.

It seemed reasonable to suppose that in the two-tone oddball condition the "fast-difficult" task was the most demanding and the "accurate-easy" one was the easiest to perform. It was hypothesized that age-dependent changes in P3b latency would be more apparent in the "fast-difficult" compared to the "accurate-easy" condition.

The amplitude of the P3 components is related to the available mental capacity engaged in the actual task. If this capacity declines in the elderly, this effect can be expected to be manifested in the decrease of the amplitude of both the P3a and P3b components. This change for the P3b would be more pronounced in the eldest subjects, especially if the speed of task execution becomes a critical factor, and/or the task is more difficult. We also hypothesized that the P3a is even more sensitive to aging than the P3b, as suggested by the frontal theory of aging. The influence of age on both components was studied in a novelty oddball paradigm. An easy frequency discrimination task was used, which, however, was made more complex by presenting three different kinds of stimuli.

4.2.1. Results

In accordance with our expectations aging effects could be observed in the later components, which indicated that cognitive processes are more affected by aging than the function of sensory-perceptual systems.

In the easy oddball task a linear increase was seen for the P3b latency, while in the difficult task a quadratic function could be fitted for the slowing of P3b latency. In this latter case information processing is under higher demand and the involved processes can delay each other producing a more expressed slowing of the latency of the P3b component.

The latency of the P3b component in the novelty oddball task was also found to increase with age, and a quadratic function could be fitted for this change also. Although discrimination of the standard and target tones was easy in this task, it is possible that ignoring novel stimuli made this condition more complex, requiring the engagement of increased processing capacities. The fact that no differences were found with respect to the number of false alarms in between the age groups indicates that increased processing required by higher task complexity, rather than inefficient inhibitory mechanisms could be responsible for the latency increase. P3b latency was the shortest in the middle age group, however, this difference was not statistically significant. Until the age of 60 years – similar to that seen in the two-tone oddball task – no significant difference was found between the age groups. Only in the eldest group was the P3b latency longer than in other groups. A possible explanation for this finding could be that although the efficiency of the mechanisms responsible for the generation of the P3b presumably begins to decline at an earlier age, the result of the accumulation of these effects becomes manifested at a later age.

P3b amplitude was found to decrease with task difficulty indicating increased demand on processing capacity. No age main effect was found in this regard, i.e. decreased processing capacity caused by aging could not be verified by our data. Contrary to our expectations, task x age group interaction was not found. These results seem to refute our hypothesis that available capacities decrease with age.

P3b scalp distribution did not change with age. One possible reason for this is that the mean age of our participants was 63.7 years while in other studies the eldest subjects are often 80 or 90 years old.

In the novelty oddball task a marginally significant age group main effect was found for the P3b amplitude which may indicate increased processing demands in the more complex task probably caused by the distracting effect of novel stimuli.

P3a latency increased and its amplitude decreased with age. In all age groups (30-70 yrs) a frontocentral scalp distribution was seen, except in the youngest group where a parietal maximum was found. This observation may be explained by overlapping neural generators activated in a different way in the age groups, with the functional distinction between an initial frontal/central P3a and a subsequent parietal P3b.

Rather than being linear, a quadratic function was also found for the latency of the P3a with age indicating that a single linear relationship seems to be too simple to account for this function. Similarly to that suggested for the P3b latency changes, it seems likely that during the course of the aging process various mechanisms, although to different degree, become simultaneously involved resulting in an acceleration of functional changes the consequence(s) of which become more apparent at later years of age.

The fact that P3a amplitude showed an age-related decrease, while that of the P3b did not, and its latency change was accelerated can be explained by the theory according to which the novelty system is less redundant than the target detection network, and hence it has less compensatory plasticity.

In sum the early processes of the sensory-perceptual systems seem to remain unaffected by aging, while the later cognitive processes change in a greater extent. One main parameter among the causes can be the difficulty of the task. In simple tasks aging effects can pass unnoticed, while in complex conditions these effects can accumulate and become even more conspicuous.

4.3. Visual oddball paradigm with emotional stimuli

Some of our decisions in everyday life are based on the quick evaluation of the visual environment. We react to the stimuli of the environment according to their emotional and motivational relevance, which requires fast processing within a few 100 ms period. These processes can be studied with the method of ERPs.

As no relevant ERP study in the literature is known, we decided to investigate how emotional stimuli affect processing of young and elderly groups in a visual oddball paradigm. We hypothesized that the ERP components connected with attention, encoding and memory processes (N1, P2, N2, P3) would change in a different way in the age groups.

Data obtained by fMRI suggest that different age groups utilize different networks for the perception of the emotional stimuli. Therefore the distribution of the analyzed components was expected to differ between the groups.

Pictures were selected from IAPS by Lang et al. on the basis of the valence and arousal scores. The standard stimulus was a neutral picture (probability: 0.85). Target stimuli were neutral (0.05), positive (0.05) and negative (0.05) pictures (duration 1s, ISI 2s).

4.3.1. Results

Earlier studies found that the two dimensions of emotional pictures have different effect on the ERP components: valence influences the earlier (100-250 ms), and arousal the later (200-1000 ms) components.

Aging effect on ERPs in an emotional visual oddball task has not been studied before. We were interested in group differences in processing negative and positive, emotional and neutral pictures. We did not investigate arousal as a distinct dimension.

Other published data are concerned with the amplitudes of the components. In our study only the P3b amplitude showed condition main effect: the amplitude was increased to emotional pictures compared to those elicited by neutral ones. Although it is in accordance with other results, it is feasible that not valence but arousal caused the difference since the emotional pictures had high, and the neutral had low arousal scores.

No age group x condition interaction was found for the amplitude of the components, but their scalp distribution differed between the groups. It is likely that different activity patterns of the networks are behind this finding, which may indicate compensatory mechanisms or the use of different strategies.

In sum, age groups did not vary in processing neutral, positive and negative emotional stimuli, but their activity pattern during this process was different.

4.4. Auditory CNV paradigm with emotional pictures

Emotional stimuli capture attention, increase arousal level and activate the organism to prepare to the adequate reaction. In our study we were interested in how their presence influences the processing in a CNV paradigm, during which neutral, positive or negative pictures were presented.

CNV is a slow negative potential in the EEG, which is the result of a widespread depolarization in the dendritic trees of cortical pyramidal neurons and indicate mobilization of attentional resources. The early subcomponent of the CNV was suggested to be related to orientation elicited by the warning stimulus and the late subcomponent reflects the anticipation of the imperative stimulus. Arousal influences the early, attention the late subcomponent of the CNV.

The generators of the CNV are – at least partly – in the frontal cortex, which is mostly affected by aging, therefore it can be hypothesized that the CNV would differ between the age groups. Data of the literature are contaversial in this field due to the differences in task difficulty and some variables that can be hardly controlled, like effort or fatigue.

We hypothesized that the amplitude of the CNV would be decreased in the elderly compared to young group during neutral pictures. The emotional pictures have an activation effect, the level of the arousal increases, stimulus processing is facilitated. This excitation during the presence of emotional pictures can enhance the amplitude of the ERP components. If the physiological reactivity of elderly is lower, the amplitude enhancement will be more pronounced in young adults.

Similarly to the fourth experiment, we studied the changes of visual ERP components as a function of the emotional content and aging. This condition differed from the visual oddball paradigm as no task was required of the participants concerning the onset of the visual stimulus.

Pairs of auditory stimuli were presented (ISI= 3000 ms, ν= 1000 Hz or 1200 Hz, 8-9 s between the pairs of tones). No task was told the participants in the control condition. In the task condition they had to press the right button if the two tones were similar (probability 0.4), and to press the left button if they were different (probability 0.6). Sometimes (probability 0.4) a picture was presented on the monitor (-1500 ms - + 5000 ms with respect to the first tone).

4.4.1. Results

4.4.1.1. Visual evoked potentials (VEP)

N1 latency showed a marginally significant condition main effect: orientation was quicker for emotional pictures than for neutral pictures in accordance with their biological relevance.

Negative valence has an effect for the late components: N2 latency was shorter, P3 latency was longer for negative pictures. Since the pictures were selected on the basis of the American scores, it is uncertain whether the effect was the result of negative valence or these pictures evoked higher arousal.

Group differences were visible mainly in scalp distribution. Young adults had a local maximum for each component, while the scalp distribution was uniform in the older group. This result indicates that different neural circuits could have activated during stimulus processing in the two groups.

To sum up one main difference was observed between the active and the passive condition: condition x age group interaction was found for the N2 amplitude in the passive task, but not in the visual oddball paradigm. N2 amplitude was decreased in the elderly compared to the young adults and did not differe between conditions. In the young group the amplitude of the N2 component decreased during the presentation of pictures in the following order: neutral, positive, and negative valence. The participants had no task concerning the pictures, hence we can conclude that the young group tried to eliminate the presence of the neutral pictures by inhibition. Processing of emotional stimuli, mainly the negative ones, is adaptive, therefore it could have been hard to eliminate their effect. Older participants may have been weaker in inhibition of irrelevant stimuli from the beginning, which was manifested in the lower amplitude.

4.4.1.2. CNV

In the task condition a CNV developed between the two tones. Its scalp distribution indicated that different processes were activated during the first and second period. In the beginning a frontal scalp distribution was seen corresponding to orientation. During the last subcomponent preparation for the motor response may have occurred manifested in a centroparietal scalp distribution.

For the young group the highest amplitude was found in the control condition in the first period, which indicates that orientation was elicited automatically by the tones. The fact that the amplitude was smaller in the task condition suggested the possibility that a slow negativity started at the appearance of the pictures and that for the young adults the picture was a warning stimulus (S1), while the first tone was a probe stimulus. If this proves to be correct, and a subsequent analysis did show the developing CNV after the picture in the young group, it was the baseline correction that decreased the amplitude of the CNV in the task condition.

The effects we hypothesized were found in the older group. The CNV developed in the task condition. The amplitude decreased for the neutral pictures compared to the condition when no pictures were presented, indicating their capacity-demanding effect. This effect was counterbalanced by the arousal increasing effect of the emotional pictures, for which the amplitudes were comparable with that seen in the absence of the pictures. It was an interesting fact that the CNV began only after the first tone in the elderly group, the appearance of the pictures did not initiate anticipation.

While differences were seen between task conditions in the elderly group, it was not observed in the young adults. The processing of visual and auditory stimuli probably took place in separate systems and the young subjects could inhibit irrelevant stimuli more effectively. The inhibitory processes of elderly adults are less effective, therefore the activation arising from different modalities did not separate and the effect of the pictures was not eliminated.

Processes discussed above are thought to be frontal lobe functions. The processes linked to motor preparation involve other cortical areas, which are less affected by aging. In compliance with this, group differences were less pronounced during the second subcomponent of the CNV.

4.4.1.3. Auditory evoked potentials (AEP)

Besides the CNV and the visual evoked potential, the AEPs evoked by the two tones were also analyzed. Aging affected the auditory P3 potentials: their amplitudes in both AEPs were decreased, and their latencies were increased in the elderly compared to young participants. N1 components showed group difference only after the first tone: its latency was longer in the elderly. According to commonly held view, this component is not affected by aging. The most probable reason for the difference is that the first tone is a probe stimulus for the young adults (and therefore its processing is facilitated) but not for the elderly.

Our findings concerning AEPs differed from those seen for the VEPs in that the distribution of the various AEP components was the same in the two age groups. The importance of stimulus modality is shown by the fact that while no group differences were observed in the distribution of AEPs recorded in the auditory oddball paradigm, this was not the case for the VEPs seen in the visual oddball experiment. It may be plausible that while no particular importance is attributed to pure tones, picture stimuli having rather complex, partly emotional content require a different type of processing which is achieved by a more extensive cortical activation in the elderly.

Our hypothesis was that emotional pictures increase arousal level and thus cause cortical activation, which results in AEP amplitude increase. According to our findings both the first and also the second P3 AEP component was larger in the presence of pictures than those observed in the control condition or in the no picture-task condition. The amplitude of the N1 component evoked by the second tone was larger in all task conditions with respect to the control condition. A main condition effect was seen for the latency of the two N1 components: orientation was faster during the presence of pictures. No difference was observed with respect to the content of the pictures, indicating an activated state of the cortex during the task (and the CNV), facilitating processing mechanisms. It seems likely that the reason why this effect was seen already for the first AEP was because the occurrence of the picture signalized the upcoming of the first tone, starting an activation process.

Even though no difference could be verified between the activating effect of neutral and emotional pictures, the effect of the pictures themselves was obvious since the amplitude of the P3 did not increase in the task condition but only when the subjects were presented these.

In summary it seems that the emotional content of the pictures did not increase significantly the activation level compared to that seen for the task. The mere presence of the pictures acting as a distracting element did influence information processing, which was different in the two age groups. Young subjects were flexible in the execution of the task using the visual input as relevant information in spite of the instruction. Elderly subjects did not deviate from instructions, they did not use the information yielded by pictures, and their presence interfered with their auditory information processing.

5. Summary

Age-related changes of the nervous system were studied by using the method of electroencephalography exploring the variables that modulate this change.

Our results can be best interpreted within the framework of the frontal hypothesis since according to our findings the frontal lobe was the most sensitive to aging effects. Omega complexity and synchronization likelihood showed group differences already in the resting EEG, which were restricted to the anterior areas. Cognitive processes take place on such a different functional background, characterized by a more efficient connectivity in the young.

ERP components requiring frontal activity were also the most sensitive to aging in the used task conditions: aging affected more the P3a component than the P3b, and concerning the CNV the age groups differed during the first period, not in the second period, where other cortical areas could have been active.

Changes of the frontal lobe can cause the decline of inhibitory processes, which were measurable in some conditions. Higher complexity in the elderly during the resting state refers to processes not necessary utilized in the current task, which decrease the efficiency of the specific processes, causing e.g. interference between different modalities.

The early processes of the sensory-perceptual systems remain unaffected, but the later cognitive processes are influenced by aging. Many variables can manipulate these effects, therefore task conditions determine whether age-related differences can be found or not. In simple tasks the effects of aging may remain unnoticed, but in complex tasks they may appear in a cumulative way. The emotional content of the stimuli can also influence the results: while the neutral pictures engaged available capacities in the old group, the activation effect of emotional stimuli eliminated the amplitude differences.

Modality and complexity of stimuli are also of significance: the scalp distribution of ERPs evoked by simple auditory stimuli did not differ between age groups, but the distribution of visual ERP components evoked by complex pictures did.

The main benefit from these experiments is to map the possible biological plasticity of the brain and its limitations that can later on be used for the compensation of aging effects. It is well known that plasticity is not lost in the elderly, although trainings are less efficient than in the young.

Determining the variables responsible for aging effect can be the goal of these experiments and also to develop useful, learnable compensatory strategies. These strategies can be effective if they are associated with basic cognitive processes that are relevant in everyday life.

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