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Research report

Preserved and attenuated electrophysiological correlates of visual spatial attention in elderly subjects

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HIGHLIGHTS

- Brain signals were measured during a covert visual spatial attention task.
- Groups of young and elderly subjects performed the task equally well.
- Stimulus-locked event-related potentials were similar for both age groups.
- Alpha power and alpha lateralization were strongly reduced in elderly subjects.
- These electrophysiological changes were consistent on the single-trial level.

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ABSTRACT

Healthy aging is associated with changes in many neurocognitive functions. While on the behavioral level, visual spatial attention capacities are relatively stable with increasing age, the underlying neural processes change. In this study, we investigated attention-related modulations of the stimulus-locked event-related potential (ERP) and occipital oscillations in the alpha band (8–14 Hz) in young and elderly participants. Both groups performed a visual attention task equally well and the ERP showed comparable attention-related modulations in both age groups. However, in elderly subjects, oscillations in the alpha band were massively reduced both during the task and in the resting state and the typical task-related lateralized pattern of alpha activity was not observed. These differences between young and elderly participants were observed on the group level as well as on the single trial level. The results indicate that younger and older adults use different neural strategies to reach the same performance in a covert visual spatial attention task.

1. Introduction

Healthy aging is associated with several neural and cognitive changes. On the behavioral level, aging is associated with a decline of many cognitive functions, such as working memory and processing speed [12,19]. On the neural level, healthy elderly people show a reduction in whole brain volume, a decline in white matter integrity, and reduced resting blood flow and metabolism, with the most prominent changes in frontal regions [12,22]. Along with structural brain changes, altered patterns of task-dependent activation are observed. Overall, older adults generally show more wide-spread activation compared to younger subjects when performing the same task [10,19,36]. In addition, healthy elderly individuals often show increased bilateral activation in frontal areas [3] and reduced posterior activation combined with increased anterior activation [12].

Electrophysiological measures of brain activity also indicate specific age-related neuronal changes. The resting state EEG of older adults shows a decrease of power in the slower cortical rhythms (delta, theta and alpha) and an increase of power in the faster beta and gamma rhythms [44]. Moreover, consistent with the decreased white matter integrity observed with structural imaging methods, the EEG also shows decreased connectivity, decreased modularity and decreased number of hubs with age [26].

Visual spatial attention refers to the cognitive process of directing attention to one location in external space, while ignoring other locations. Events at the attended location are processed faster [35] and more accurately [13] than events at unattended locations. Spa-

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tial attention is reflected in the amplitude of several event-related potential (ERP) components, including N1, P1 and P3, which are larger in response to stimuli occurring at attended as compared to unattended locations [8,33]. Additionally, oscillations in the alpha band (8–14 Hz) from posterior brain areas show a particular topography depending on the direction of visual spatial attention: when attention is directed to one half of the visual field, an increase in alpha power is observed over ipsilateral posterior areas, while alpha power decreases over contralateral posterior areas [23,47].

Performance on visual spatial attention tasks appears stable with increasing age [9,20,21]. However, there are indications that the neural activity underlying spatial attention changes with age. In the first place, resting-state fMRI research shows decreased connectivity within the dorsal attention network [1]. Secondly, elderly subjects who perform the Posner cueing task show an increased latency of the early ERP components P1, N1 and Nd1 [9]. In addition, the attention-related P3-component of the ERP has a reduced amplitude, increased latency and a more frontal topography in elderly as compared to young subjects [5,18,34,43]. Finally, a recent study by Hong et al. [21] showed an absence of alpha lateralization in older adults during a spatial attention task.

The traditional approach to study spatial attention-related brain signals is to collect a large number of trials and compute an average brain response over all subjects and trials. While averaging over many trials has the benefit of improving the signal to noise ratio, subtle changes in the brain responses between trials are lost. To overcome this problem, the grand average approach can be complemented by single trial analysis using machine learning techniques. It has been shown before that the direction of spatial attention can be reliably decoded from single trial ERPs [15,41] and single trial alpha lateralization [25,40]. The accuracy with which the direction of attention can be decoded is a measure of the consistency of the brain signals on the single trial level: the more consistent the brain response in every single trial, the more reliably the direction of attention can be decoded.

In this experiment, we measured spatial attention-related ERPs and alpha lateralization in young and elderly subjects. We expected to replicate the previously reported changes in the ERP (i.e. reduced amplitude, increased latency and more frontal distribution) and the absence of alpha lateralization as found by Hong et al. [21]. Apart from alpha lateralization, we also investigated the strength of overall occipital alpha power, because we hypothesized that the absence of alpha lateralization in elderly subjects may result from a decrease of alpha activity itself in the elderly brain [39,44]. In addition to alpha activity, we looked for age-related power changes in frequencies outside the alpha band to investigate whether information that is represented in the alpha band in younger subjects may shift to other frequencies in elderly subjects. To answer these questions, we compared the grand average brain signals of young and elderly subjects and used machine learning techniques to investigate the consistency of age-related changes on the single trial level.

2. Methods

2.1. Participants

Ten young participants (6 female), aged 19–29 (mean 25) years old and ten elderly participants (3 female), aged 66–76 (mean 69) years old, participated in this experiment. Subjects did not report any neurological or psychiatric abnormalities, had normal or corrected to normal vision, and did not use psychoactive medication. The experiment was approved by the ethical committee of the Faculty of Social Sciences of the Radboud University and all participants gave written informed consent prior to the experiment.

2.2. Materials

EEG was recorded with 64 sintered Ag/AgCl active electrodes (BioSemi, Amsterdam, The Netherlands), placed according to the international 10–20 system, at a sampling rate of 2048 Hz. Simultaneously, eye gaze was recorded with an EyeLink 1000 eyetracker (SR Research Ltd., Ontario, Canada) at a sampling rate of 1000 Hz. The subject's head was stabilized on a chin rest. Visual stimuli were presented on a 17" TFT screen with 800 × 600 pixel resolution and a refresh rate of 60 Hz.

Subjects were seated in front of a table. The screen and the eye-tracking camera were placed in the middle of the table at a distance of approximately 60 cm from the subject. A button box was placed directly in front of the subject.

2.3. Stimuli

A schematic representation of the stimuli is shown in Fig. 1b. A fixation cross of 1 × 1 cm (1.0° × 1.0°) was presented in the middle of the screen, with two squares 5.5 cm (5.2°) to the side and 2.2 cm (2.0°) below the fixation cross. The squares were 4.2 × 4.2 cm (4.0° × 4.0°) in size.

During trials, the color of the squares alternated between pure red, green and blue, with the color intensity depending on the experimental condition.

2.4. Task

The task was designed to allow for simultaneous measurement of stimulus-locked ERPs and alpha lateralization. A schematic overview of a trial is shown in Fig. 1a. Each trial started with a baseline period, followed by an arrow pointing either to the left or to the right square for 1 s. Then the squares changed color 26 times with the time between color changes depending on the experimental condition. The subjects' task was to count the number of times the square on the side indicated by the arrow turned red. The sequences of color change on the left and right were independent from each other with the restriction that the left and right squares were never red simultaneously. In each sequence both squares turned red six, seven or eight times, with equal probability.

At the end of the trial, subjects were asked to indicate with a button press how many times the square on the indicated side had turned red, choosing from the answers 5 to 8. Although the number of red squares in a sequence never equaled 5, this alternative was presented in case subjects missed one of the red color changes. While subjects performed the task, their eye gaze was monitored online. In an attempt to maintain subjects' motivation level, points were awarded at the end of each trial, subjects received points for a correct answer and for maintaining eye gaze on the fixation cross throughout the trial.

Participants first completed a practice block, followed by 30 trials for each of the four experimental conditions, divided into six blocks of approximately 10 min.

2.5. Conditions

Age is associated with a decline in sensitivity and speed of visual perceptual processing [16,22]. Therefore, we included four conditions with different color intensity and speed, so that we would be able to match the behavioral performance of the age groups by selecting the conditions on which the performance was most similar. The conditions consisted of the four possible combinations of two levels of color intensity and two rates of color change. Each subject participated in all conditions, with the order of conditions counterbalanced across subjects.