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Aging and working memory performance: Electrophysiological correlates of high and low performing elderly

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ABSTRACT

In this study we investigated age-related changes in WM capacity and their respective ERP correlates. We explicitly addressed the differentiation between high and low performing elderly to identify electrophysiological correlates of successful aging. Therefore, ERP and behavioral data was obtained from 45 young (mean = 22.73 years) and 35 older participants (mean = 68.49 years). Both groups performed a visual-spatial *n*-back task with two levels of difficulty. Additionally, related neuropsychological tests were administered. Older subjects performed less accurately in both conditions of the *n*-back task. Older age was additionally associated with a reduced fronto-central positivity (labeled as P200) in the 2-back task and an overall reduced amplitude of the parietal positivity (labeled as P300). The latter shifted to frontal leads in older subjects. Additionally, only in the group of the older participants, increased P200 and decreased parietal P300 amplitudes correlated with performance. Regarding older high and low performers, we observed a clear shift of frontal activity of both ERP components in the group of high performers. High performers additionally performed better in spatial working memory, verbal learning, and fluid intelligence tasks. We conclude, that increasing demands of working memory load are accompanied by a reallocation of resources in both young and older adults. With age, executive control and updating processes (indexed by both ERP components) are diminished or rely on more frontal processes for compensation. However, high performing older adults, who perform comparable to young adults, sustain comparable executive control processes, exceeding pure compensation.

1. Introduction

The process to maintain and manipulate information over a short duration of time has been termed working memory (WM; Baddeley, 1992, 2003). WM has been assumed to play a major role in other cognitive functions such as intelligence and reasoning, learning and comprehension (Baddeley, 2003; Conway et al., 2003). Models on WM also consider the complexity of this function, which includes sensory processing of the information, its storing in a short-term buffer, updating, and allocation of resources via executive control. The properties of these processes are detailed in several review papers (Baddeley, 2000). In experimental settings, the *n*-back task has been widely used to study WM (Gevins and Smith, 2000; Gevins et al., 1996; McEvoy et al., 2001; Missonnier et al., 2004, 2003; Watter et al., 2001). For this task, especially updating processes as well as matching stimuli to those encoded in WM are required (Watter et al., 2001).

The neural implementation of WM has been the topic of neuroimaging studies, concluding that a stronger fronto-parietal connectivity is related to higher WM capacity (Braver et al., 1997; Edin et al., 2009; Ekman et al., 2016; Linden, 2007). The time course of WM activation has also been tracked in electroencephalographic (EEG) studies using event-related brain potentials (ERPs) (Gevins et al., 1996; McEvoy et al., 1998; Missonnier et al., 2003; Ruchkin et al., 1992). Two components were reliably observed when participants were engaged in a WM task: the P200 and the P300. Both have been found in the aforementioned tasks assessing WM.

The fronto-central P200, a positive voltage deflection in the interval between about 170–270 ms following stimulus onset, is assumed to reflect attentional processes, mainly the initial awareness of a presented stimuli and the allocation of attention (Lijffijt et al., 2009) and at least for auditory processes, the ability to inhibit or disengage from irrelevant stimuli (Amenedo and Díaz, 1998). In line with these interpretations, Zhao et al. (2013) argued that the P200 is an indicator for executive attention. The term was introduced by Engle et al. (2002), who proposed that WM capacity is not due to memory capacity but highly dependent on the ability to control attention and therefore maintaining (or suppressing) information in an active state, especially when faced with interfering distractors.

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Alternatively, the frontal P200 is thought to reflect motivational salience, as a result from the novelty of a stimulus or its task relevance and was shown to increase with age (Potts, 2004; Riis et al., 2009).

The centro-parietal P300, a positive voltage deflection in the interval between about 300 and 500 ms, has been established as a marker for updating processes in WM within the framework of the context updating hypothesis (Donchin and Coles, 1988). The P300 amplitude also reflects the WM load: When concurrent information needs to be held active, the P300 amplitude is reduced, indicating the allocation of resources necessary for other mental activities, i.e. holding information in WM. In contrast, a larger amplitude was found when attention can be focused on one stimulus and is not consumed by other mental activity (Gevins et al., 1996; McEvoy et al., 1998). The P300 amplitude also reflects inter-individual differences in WM capacity (Gevins and Smith, 2000), as well as the effect of a WM training (Zhao et al., 2013).

ERP methods have also been used to study the effects of aging on WM. It has been established that WM performance declines with advanced age, especially in the visuospatial domain (Jenkins et al., 2000; Park et al., 2002). Older individuals, approximately around the age of 60, show a decreased WM capacity as well as the ability to manipulate information (Dobbs and Rule, 1989; Fisk and Warr, 1996). Accordingly, age-related WM changes have also been found in neuroimaging (Gazzaley et al., 2005; Mattay et al., 2006; Reuter-Lorenz et al., 2000) and EEG-studies (McEvoy et al., 2001; Missonnier et al., 2004, 2011; Saliasi et al., 2013). Regarding the latter, both, the P200 and the P300 have been demonstrated to be modulated by age, although the direction of the effects was not always consistent. Whereas McEvoy et al. (2001) found an increase in the P200 amplitude with advancing age, Missonnier et al. (2004) found a reduction of a phasic (positive-to-negative) waveform in a comparable time windows (140–280 ms) in older participants. Findings on the P300 were less controversial. With increasing age, a reduction of the positive amplitude was found, and the effect was focused at parietal leads (McEvoy et al., 2001; Saliasi et al., 2013; Wild-Wall et al., 2011).

At first sight, the above mentioned ERP studies apparently support the notion of age-related changes in a fronto-parietal network supporting WM operations. McEvoy et al. (2001) concluded that whereas in younger participants parietal areas seem to be more involved, older subjects rely more on frontal areas for task completion. However, the inconsistent findings on the direction of the P200 parallel differences in behavioral results: Whereas McEvoy et al. (2001) failed to find a decrease in performance in the high load task in older participants, Missonnier et al. (2004) on the other hand found that older participants performed worse than younger ones in this task. The first finding accompanied by an increase of the P200 amplitude in older subjects indicates the successful compensation of an age-related decline, whereas the second one is accompanied by reduction in amplitude supporting the idea of decreased brain reserve in aging. We assume that the inconsistencies between the aforementioned studies are partially due to the neglect of the level of performance: heterogeneity is caused by inter-individual differences within an age group, which might lead to different results, based on the sample characteristics.

First empirical evidence supporting the effect of inter-individual differences on WM performance and associated electrophysiological correlates is provided by Daffner et al. (2010). When WM demands increased, high performing young and high performing older participants had more pronounced P300 amplitudes as contrast to low performing participants. Splitting up age groups based on performance additionally allows to identify factors responsible for ‘successful’ vs. ‘usual’ aging (Rowe and Kahn, 1987), terms coined for older adults that show no cognitive loss compared to those who show an age-related decline in their cognitive abilities.

Therefore, our study on age-related behavioral and electrophysiological changes in a visual-spatial *n*-back WM task explicitly addressed the differentiation between old high and low performers. In order to examine the neuropsychological profile of the participants in more detail, we also considered psychometric measures of related cognitive functions to determine, to which extent WM capacity is linked to these associated cognitive functions. We will focus on the following points:

First, we want to examine the age-related effects on WM performance, and its ERP correlate. We hypothesize older participants to perform worse to younger ones, with a more pronounced decrease of performance in a high-load condition. Consistent with previously mentioned studies (Gevins et al., 1996; McEvoy et al., 1998), we expect a reduction of the P300 amplitude for the higher load task, with a further reduction for older participants. A more-pronounced utilization of more executive processes is expected to result in a P200 increase for the higher memory load task for older participants (McEvoy et al., 2001).

Second, we want to explore, whether changes in ERP components are related to individual performance in the *n*-back task and whether a relationship with other cognitive functions, such as processing speed, general learning, and fluid intelligence exists. Of interest is the identification of other cognitive functions related to the performance of the *n*-back task, and how this relation is affected by aging.

And finally, regarding performance level, we expect amplitude changes in the older participants in relation to their performance level. In line with the compensation hypothesis of McEvoy et al. (2001), we expect an increase of the P200 for high performers with increasing demands on WM. In contrast, we expect an amplitude decrease for low performers, as a sign of inefficient processes and decreased brain reserve as proposed by Missonnier et al. (2004). Regarding the P300, we expect an increase in amplitudes for high performers in a highly demanding condition.

2. Methods

2.1. Participants

Ninety healthy adults of two age groups (young vs. older) were recruited for this study. The group of the younger participants comprised 45 individuals (34 females) with a mean age of 22.73 years (*SD* = 3.47 years). Forty-four of the participants had a general qualification for university entrance. For the group of the older participants, 35 individuals (25 females) with a mean age of 68.49 years (*SD* = 4.95 years) were tested in our study. Participants of the older group were selected for comparison with the young participants based on their educational level. Accordingly, 24 participants had a general qualification for university entrance. Since only cognitive healthy older participants were to be included in the analysis, the Mini Mental Status Examination (MMSE; Folstein et al., 1975) was conducted only in this group. The mean score of 29.47 (*SD* = .95) indicates that only cognitive healthy elderly individuals were included. Written consent was obtained from all participants.

Exclusion criteria encompassed degenerative neurological conditions and non-correctable deficits in vision. Furthermore, participants were excluded because of EEG artifacts or alpha-EEG and if a high number of false alarms during the completion of the *n*-back task indicated, that task instructions were not understood (number of false alarms higher than hits in 1-back task). Altogether, ten participants of the younger group and five participants of the older group had to be excluded, leaving 35 participants (27 females) in the younger group (mean age = 22.43 years, *SD* = 3.25 years) and 30 participants (22 females) in the older group (mean age = 68.30 years, *SD* = 5.19 years) for analyses. Based on the results of a previous study (Daffner et al., 2010), we expected a medium-sized effect of aging. A power analysis using G*Power (Erdfelder et al., 1996) indicated that a total sample of 64 participants would be needed to detect medium effects ($\eta_p^2 = .10$, adjusted to the taxonomy of Cohen, 1988) with a 80% power using a *F* test with alpha at .05.

Because we wanted to identify the characteristics of successful