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Age-related effects on verbal and visuospatial memory are mediated by theta and alpha II rhythms

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ABSTRACT

Both electrical brain activity during rest and memory functions change across the lifespan. Moreover, electrical brain activity is associated with memory functions. However, the interplay between all these effects has been investigated only scarcely. The present study investigated the extent to which the power of resting-state electroencephalographic (EEG) frequencies mediates the impact of aging on verbal and visuospatial memory. Seventy healthy participants with 22 to 83 years of age completed a visuospatial and verbal learning and memory test and provided eyes-open and eyes-closed resting-state EEG data. Robust age-related effects on behavioral and EEG data were observed. Mediation analyses showed that the relative power of the theta (4–8 Hz) frequency band in fronto–central locations partly explained the negative age-related effect on delayed recall in the verbal memory task. The relative power of the alpha II (10–12 Hz) frequency band in mainly parietal locations partly explained the negative impact of age on immediate and delayed recall in the visuospatial task. Results indicate that spontaneous brain activity carries specific information about aging processes and predicts the level of competence in verbal and visuospatial memory tasks.

1. Introduction

Across the lifespan, cognitive functions as well as brain activation patterns change. While a large body of literature reports on changes of either spontaneous brain activation or cognition with age, the interplay between age, brain activity and cognitive functions has been only scarcely investigated. Spontaneous brain activity may carry information about aging processes and may predict the level of competence in specific cognitive tasks. Thus, the aim of the present study was to investigate the extent to which power of resting-state EEG frequencies explains the impact of aging on memory capacity.

Numerous studies have shown that a decay of episodic memory capacity is found across the lifespan (Verhaeghen et al., 1993), with most declines occurring after the age of 60 (Rönnlund et al., 2005). Age-related declines have been shown for both the verbal memory domain (Hoyer and Verhaeghen, 2006; Jenkins et al., 2000; Nilsson, 2003; Small, 2001; for a review see Zacks et al., 2000), and for visuospatial memory (Bopp and Verhaeghen, 2007; Jenkins et al., 2000; Murre et al., 2013; Salthouse, 2003). However, it remains an open issue whether the pattern of age-related decay is the same in these two domains. Results of a study by Park et al. (2002) indicate that the decline of verbal and visuospatial memory proceeds at the same rate across decades. This is also supported by a study of Salthouse (1995), who found little evidence for a difference between age-related effects on verbal and on visuospatial memory. In contrast, Jenkins et al. (2000) found visuospatial memory to be more affected by age than verbal memory: In this study, older adults showed more deficits regarding the processing and memorizing of visuospatial than of verbal information when compared to younger adults. Moreover, in a recent online study by Murre et al. (2013) with 28,000 participants, the decrease of visuospatial memory was found to advance twice as fast as the decrease of verbal memory. To shed more light on this topic, we placed a special emphasis on the differentiation of verbal and visuospatial memory. Therefore, two structurally and conceptually highly similar tasks assessing verbal and visuospatial memory were completed by participants of different age groups.

In addition to the age-related effects on memory functions, age also induces changes in the electrophysiological oscillations of the brain. Robust age-related effects have been reported in the theta (approx. 4–8 Hz) as well as in alpha II (approx. 10–12 Hz) frequencies. Several studies have investigated the development of alpha rhythm across the lifespan and most report a decrease of alpha rhythm power in healthy adults during the late part of the lifespan (Babiloni et al., 2006; Klimesch et al., 1999; Rossini et al., 2007). The power of slower frequencies such as theta (approx. 4–8 Hz) and delta (<4 Hz) on the other hand, has been reported to increase with aging, an effect named “slowing” of

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the EEG with age (Klimesch et al., 1999; Rossini et al., 2007). However, findings on this effect are divergent (Rossini et al., 2007), as several studies have not found an increase of theta frequency band power with age (Cummins and Finnigan, 2007; Puligheddu et al., 2005; Vlahou et al., 2014; Wang and Hsieh, 2013). Cummins and Finnigan (2007) even observed decreased theta power in older persons when compared to healthy young persons in a cross-sectional study. One reason for these divergent findings could be the variety of methods applied for analysis of resting EEG power data. For example, some researchers report absolute power values, while others use relative power values. Also, comparability of findings across studies is limited as some research groups use individually adapted frequency bands while others use 'traditional' fixed frequency bands (see Klimesch et al., 1999 for a discussion). In summary, although the literature is not conclusive regarding the direction, specificity and intensity of age-related effects on EEG frequencies, one may be confident about their existence.

Furthermore, brain oscillations play an essential role in inter-individual differences observed in cognitive processing (Buzsáki and Draguhn, 2004). Especially alpha (approx. 8–12 Hz) and theta (approx. 4–8 Hz) frequencies have been linked to memory functions. The relation between theta power and memory functioning is still a matter of debate: On the one hand, decreased resting theta power (approx. 6–9 Hz) has been related to better performance in cognitive tasks (Klimesch et al., 1999). Moretti et al., 2009 found that in persons suffering from mild cognitive impairment (MCI), a decreased theta/gamma ratio was associated with better performance in memory tests. Moreover, memory-related brain structures and theta power seem to be connected: In a study by Grunwald et al., 2007, higher EEG theta resting power was significantly correlated with decreased hippocampal volume in a sample of different stages of cognitive impairment. On the other hand, Finnigan and Robertson (2011) found that relative resting-state theta power (4–6.5 Hz)[1] correlated positively with cognitive performance (immediate and delayed recall, executive function tasks, attention measures) in healthy older adults and thus suggested high resting theta power might be a marker of healthy aging. As stated by Finnigan and Robertson (2011) the inconsistent evidence regarding the relation between resting theta power and cognitive functioning might be explained by the existence of two distinct types of theta oscillations: One indicating healthy neurocognitive aging while the other is more related to EEG alpha slowing and disturbances in brain functioning and associated with future cognitive decline. Further evidence of a positive association between theta power and cognitive performance was reported in a recent neurofeedback study: Wang and Hsieh (2013) found that up-regulation of frontal midline theta (4–7 Hz) led to an increase in working memory function in older participants.

Evidence regarding alpha power is more homogeneous with most studies reporting that higher resting-state alpha power, especially in the alpha II range (approx. 10–12 Hz) is associated with better performance in memory tasks (Klimesch et al., 1999; Lopez Zunini et al., 2013; Vogt et al., 1998). Recent results of a neurofeedback study also indicate a link between alpha power and memory: In a study by Nan et al. (2012), an increase of relative individual upper alpha frequency amplitude during neurofeedback training was related to improved short term memory capacity after training.

Although it is clear that memory decreases with age, the mechanisms underlying this age-related decay remain highly debated. As shown above, both memory capacity and resting EEG change across the lifespan. Moreover, resting EEG and memory capacity are associated with each other. Although the existence of these effects is well documented, not much is known about how these effects are related to each other and to which extent they are independent of each other. In MRI research, structural equation models have been used to explore the relation between age, cognition and brain structure/functioning: Rabbitt et al. (2007) investigated neurophysiological markers of aging (global age-associated atrophy, white matter lesions, cerebral blood flow) and used structural equation models to assess their relationship with age and cognitive test scores. Several markers, especially those measuring speed of information processing, could successfully be used to explain part of the effect that age had on performance in cognitive tasks. Thus, results indicated that neurophysiology changes dramatically across the lifespan and might be largely responsible for the age-related decline of cognitive functions.

To our knowledge, no EEG investigation has been carried out on the exact relationship between all these effects. The extent to which age-related effects on memory capacity are also shared by resting EEG has not been investigated directly. Moreover, the topography of these age-related effects has not been determined accurately. As observed in previous studies, age-related effects on physiological parameters of brain functioning may impact different regions of the brain in different and even opposite directions (Wood et al., 2009). In the present study, the strength and topography of mediation of age-related effects through different frequencies of resting EEG was examined. First, the age-related effects on measures of memory capacity and its specificity regarding verbal and visuospatial processes were assessed. Second, the age-related effects on specific bands of resting EEG were assessed. Finally, the extent to which the impact of aging on memory capacity is mediated by specific bands of resting EEG was evaluated. To investigate this, we assessed resting EEG and memory capacity in a sample of individuals with a large age range. Two tasks with known psychometric properties and high structural similarity were employed to refine the investigation of age-related effects on verbal and visuospatial memory processes.

2. Methods and materials

2.1. Participants

Healthy participants aged between 22 and 83 (mean = 47.67, SD = 17.83) took part in this investigation. Participants were included in the present study only if according to self-reports obtained during a standard anamnesis protocol, no present or past chronic degenerative or any other form of neurological/psychiatric disorder was present. Accordingly, participants were not making use of any medication related to these disorders. Moreover, participants took part in an extensive individual cognitive assessment involving the main cognitive functions working memory, short-term memory, long-term memory and attention. Inspection of individual normed scores revealed no systematic cognitive deficits in participants of any age group. For the sake of clarity, further details of the cognitive screening will not be reported. The sample's demographic characteristics are depicted in Table 1. It was ensured that participants of all age groups had received a minimum of 9 years of education and the proportions of individuals with more than 12 years of formal education in each age group are statistically comparable to the Austrian population average (all p-values $p > 0.07$). Participants' visual impairments, if present, were corrected by use of glasses or contact lenses. Participants were recruited from the general population by public bulletins and newspaper announcements. They were either paid an expense allowance of 8 Euro/h or (in the case of psychology students) received course credits. The study was approved by the ethics committee of the University of Graz, Austria and all participants gave their written informed consent before participation.

2.2. Procedure

EEG recordings and the verbal and visuospatial memory tasks took place in two separate sessions occurring on successive days. On the first day, the visuospatial and verbal memory test (VVM2, Schelling and Schächtele, 2001) was used to assess short and long-term retention ability of explicit verbal (construction task) and visuospatial material (city map task).

[1] Assessed as the ratio of absolute theta power to total power across the 1–30 Hz range.