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Stress-related deficits of older adults' spatial working memory: an EEG investigation of occipital alpha and frontal-midline theta activities

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ABSTRACT

Studies highlight cumulative life stress as a significant predictor of accelerated cognitive aging. This study paired electrophysiological with behavioral measures to explore how cumulative stress affects attentional and maintenance processes underpinning working memory retention. We collected electroencephalographic recordings from 60 individuals (30 older, 30 younger) reporting high or low levels of cumulative stress during the performance of a spatial Sternberg task. We measured mid-occipital alpha (8–12 Hz) and frontal-midline theta (4–6 Hz) as indicators of attentional and maintenance processes. Older, high-stress participants' behavioral performance lay significantly below than that of younger adults and low-stress older individuals. Impaired task performance coincided with reduced event-related synchronization in alpha and theta frequency ranges during memory maintenance. Electrophysiological findings suggest that older adults' reduced performance results from a stress-related impact on their ability to retain a stimulus in working memory and inhibit extraneous information from interfering with maintenance. Our results demonstrate the wide-ranging impact of cumulative stress on cognitive health and provide insight into the functional mechanisms disrupted by its influence.

1. Introduction

Deficits of cognitive functioning are an established co-occurrence of aging (Colino et al., 2017; Hahn et al., 2011; Salthouse and Babcock, 1991; Vasquez et al., 2014). However, age-related cognitive decline is not uniform as several biological and environmental factors have been shown to influence its trajectory. These range from genetic makeup (Bis et al., 2012; Stessman et al., 2005) to certain lifestyle choices such as physical activity and dietary intake (Chang and Etnier, 2009; Tedesco et al., 2000). A further determining factor highlighted by past work is the amount of stressful experiences individuals encounter during their lifetime. The impact of stress on cognitive aging has only recently gained scientific interest. However, since then, several studies have demonstrated that cumulative life stress has a significant impact on cognitive integrity in old age (Dickinson et al., 2011; Munoz et al., 2015; Pesonen et al., 2013). This is not surprising as prolonged exposure to the stress hormone cortisol (glucocorticoids) results in pronounced oxidative damage to areas of the hippocampus and neocortex (Ohl et al., 2000; Shao et al., 2015), brain structures integral for intact executive functioning and memory performance. Stress-induced hippocampal damage has been attributed to glucocorticoids causing a prolonged reduction of glucose reuptake into hippocampal cells (Sapolsky and Meaney, 1986), which results in dendritic atrophy and an inhibition of neurogenesis. Frontal damage is thought to be sustained by an increased number of micro lesions produced by stress-induced hypertonic strain on arteries and veins (Rabbitt, 2005).

Correspondingly, our own work comparing older and younger participant groups with high and low levels of cumulative stress demonstrates stress- and age-related behavioral deficits in the realms of inhibitory control and working memory (WM) (Marshall et al., 2015, 2016a). For WM, we demonstrate that behavioral shortcomings among older high-stress adults coincide with aberrant patterns in the alpha (8–12 Hz) and theta (4–6 Hz) frequency ranges. Specifically, studying WM with a standard version of the Sternberg paradigm (Sternberg, 1966) revealed significantly reduced alpha event–related activity across the parieto-occipital scalp regions of older high-stress adults during periods of memory maintenance (Marshall et al., 2015), highlighting that stress may impact on older adults' ability to successfully inhibit task

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irrelevant brain regions. Our work thus suggests that, among older adults, cumulative stress has a detrimental impact on oscillatory processes contributing to the successful retention of stimulus material. Findings to this effect highlight the efficacy of pairing behavioral with neurophysiological markers of cognitive functions as the latter provide an insight into the cognitive mechanisms affected by lifetime stress exposure. We extended this work by introducing a spatial component to the WM process by means of an object location memory task (Reagh et al., 2014). This revealed a global change of theta activity during the recall of stimulus material, which was specific to older adults with high amounts of lifetime stress (Marshall et al., 2016b). However, this spatial paradigm did not afford the opportunity to investigate theta activity during WM maintenance. As our past work shows that cumulative stress compromises the maintenance period, this constitutes a necessary extension to investigating the effects of stress on spatial WM. In the present study, we thus explored stress- and age-related changes to the alpha and theta bands during encoding and maintenance periods of a spatial Sternberg paradigm. In addition to extending our work, this also afforded the opportunity to replicate the observed effect of stress on cognitive aging. The impact of stress on cognitive integrity is a recent discovery. Therefore, it does not yet have a large reference body. Given the replication crisis for psychological studies and the crucial impact of these findings for health and well-being, it is imperative to provide sound replications of this effect.

The paradigm used in this study was developed by Lenartowicz et al. (2014) who demonstrated that it successfully captures task-related changes in occipital alpha and frontal-midline theta (FMθ) activities. We measured electroencephalographic (EEG) neural responses to this task in a sample of older and younger individuals who reported varying degrees of stressful life encounters. We analyzed EEG signals using a combination of highly controlled, permutation-based, mass univariate analyses and time-frequency analysis to focus on mid-occipital alpha and FMθ as established correlates of attention/inhibition and memory maintenance, respectively. Based on our foregone work, we predict that members of the older age, high-stress group will show significantly reduced alpha and theta event-related activity relative to both younger and older low-stress group members. We expect this effect to manifest in encoding and maintenance phases of our task. In the encoding phase, we expect reduced event-related desynchronization of the alpha frequency range. In the maintenance phase, we predict reduced event-related synchronization of the alpha and theta frequencies among older adults with high levels of lifetime stress.

2. Materials and method

2.1. Participants

Thirty young adult participants (14 females; mean age = 22.5, standard deviation [SD] = 3.18; range = 18–30 years) were recruited from the University of Essex student population via institutional e-mail advertising. A second group of 30 older participants (18 females; mean age = 68.73, SD = 4.65; range = 61–79 years) were recruited from regional clubs and societies and via advertisements placed in local newsletters. Age ranges (18–30 younger; 60–80 older adults) were specified in the advertisement. They were chosen based on a reference body of work comparing cognitive effects between younger and older adults (Fandakova et al., 2014; Isingrini et al., 2015; Reuter-Lorenz et al., 2000) as well as our own previous studies observing robust electrophysiological differences between age groups from similar ranges (Marshall et al., 2015; Marshall et al., 2016a,b). Exclusion criteria specified during recruitment included major medical conditions (i.e., diabetes, heart disease), major neurological damage (i.e., stroke), and a current diagnosis of a mental or psychiatric disorder (dementia, depression, or anxiety disorder), as well as the use of psychoactive medication or a history of substance abuse. To ensure against undiagnosed cognitive pathologies, all older participants completed the mini-mental state examination for which all scored within the normal range (>24 marks). All participants provided written informed consent. The study was approved by the University of Essex Ethics Committee.

2.2. Stress and demographical measures

Demographics included participants' age, level of education, amount of cigarette and alcohol consumption, levels of physical activity, and whether they were currently suffering discomfort from a physical disability that might impact on their task performance. In addition, levels of trait and state anxiety were assessed using the State Trait Anxiety Inventory (Spielberger et al., 1968). We used the State Trait Anxiety Inventory to test for individuals with exceptionally high state or trait levels of anxiety as these may confound the effect of lifetime stress on cognitive performance. Scores on both subscales remained low and an established method to define and detect outliers (Tukey, 1977) did not find any individuals who greatly deviated from the sample mean. In line with our previous work (Marshall and Cooper, 2017; Marshall et al., 2015, 2016a,b), we assessed the number of participants' stressful experiences using the Social Readjustment Rating Scale (Holmes and Rahe, 1967) for older and the Student Life Events Scale (Clements and Turpin, 1996) for younger adults. Both scales have been validated for respective student and adult population samples and have been shown to provide valid and reliable estimates of cumulative stress (Clements and Turpin, 1996; Gerst et al., 1978; McGrath and Burkhart, 1983). The choice for using different stress inventories for each age group has several reasons. First, older adults were on average 3 times the age of younger participants and thus likely to have experienced more stressful events relative to our young participant sample. Second, these stressful experiences had a high likelihood of being qualitatively different between both age groups. Thus, to assess prolonged stress exposure appropriate to each age group, different instruments had to be used for each age group. Chosen scales were selected based on an identical format to assess life experiences. Each consists of a brief, self-administered scale (43 and 36 items, respectively). Items are weighted according to magnitude so that "death of a spouse/parent" carries a high score of 100 while a mildly stressful incident such as "vacation with family or friends" has a low score of 16 (Student Life Events Scale) or 13 (Social Readjustment Rating Scale). Scores range from 0 to 1466 for the Social Readjustment Rating Scale and from 0 to 1849 for the Student Life Events Scale. Higher scores reflect high amounts of experienced stress for both scales. Both scales are commonly used to assess life events occurring in the past year. To assess the cumulative, lifetime impact of stressful events, we thus modified the instructions. Participants were asked to indicate which events they remembered occurring in their lifetime. We urged participants to be stringent in their assessment and to name only those events they could explicitly remember. Our previous work demonstrates that this modification does not result in ceiling effects for the number of events reported and produces lifetime stress scores that reliably predict variance in cognitive task performance (Marshall and Cooper, 2017; Marshall et al., 2015, 2016a,b). As in previous studies, scores on each scale were used to divide both age groups into high- and low-stress scorers. The divide was based on the median split of scores from the Social Readjustment Rating Scale for older adults (value: 628) and the Social Readjustment Rating Scale for younger adults (value: 574). No significant group differences in mini-mental state performance, age, gender, educational attainment, cigarette/alcohol