International Journal of Psychophysiology 117 (2017) 17–25

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

The interconnection of mental fatigue and aging: An EEG study

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ARTICLE INFO

Keywords:
Mental fatigue
Aging
Theta
Alpha
Frequency analysis

ABSTRACT

Mental fatigue, a state of reduced alertness and decreased overall performance due to prolonged cognitive activity, is a major cause for a large number of accidents in traffic and industry. Against the background of an aging workforce, the investigation of the interconnection of mental fatigue and aging is of great practical relevance. In the present study, a group of younger and a group of older adults performed a cognitive task for 3 h. The experimental design also comprised breaks with various durations. Beside behavioral data, the spectral properties of the ongoing EEG with respect to time on task and breaks were analyzed. No differences between the age groups were found in behavior, but electrophysiological measures provide some evidence that older adults in our study were differentially affected by time on task. In the later course of the experiment modulations in frontal theta power became larger for older, compared to younger adults. This may indicate strain due to task demands, eventually resulting from the deployment of compensatory processes. Occipital alpha, which has been linked to internally oriented brain states, saturates faster in younger adults. It thus maybe, that especially the younger participants' performance deteriorated due to the monotonous nature of the task itself. Both mechanisms, an increased consumption of cognitive resources in older adults and a decrease of motivation in younger adults, could mask differences in performance decrements between the age groups due to mental fatigue.

1. Introduction

In modern working environments it is of great importance to maintain performance at sufficient high levels, even in longer work shifts and when the task itself is rather monotonous. One challenge in maintaining task performance is the fact that cognitive work can lead to a state of mental fatigue, which is characterized by reduced mental alertness and a decrease of performance. Mental fatigue-related unintentional human error contributes to a large amount to accidents in industry and motor vehicle crashes (Dinges, 1995). It is often seen as a cumulative process (Lal and Craig, 2001), resulting in a constant decline of performance over time that is also labeled as a time on task effect. A negative impact of mental fatigue could be found for a number of cognitive functions, such as error processing (Lorist et al., 2005), executive control processes (van der Linden et al., 2003) and goal-directed (top-down) attention (Boksem et al., 2005). Mental fatigue has been defined in terms of motivation, as a feeling of weariness with the participants' unwillingness to continue to perform in the task at hand as the core aspect (Grandjean, 1979; Tops and Boksem, 2010). However, the construct mental fatigue is not unidimensional. It still remains unclear, to which extent a depletion of cognitive resources and motivational factors are responsible for the decline of performance in a given situation (Boksem et al., 2006; Boksem and Tops, 2008; May and Baldwin, 2009). Craig et al. (2006), for example, found a poor association between behavioral and physiological measures of mental fatigue on the one hand, and self-report of fatigue and psychological variables on the other hand. This further outlines the difficulty to define mental fatigue as a homogeneous construct. A similar pattern of cognitive decline as in fatigued participants can be seen in older adults. Thus, it is not surprising that older adults may show rapid mental fatigue when performing in a long lasting task (Wascher and Getzmann, 2014). The present study aims to uncover this relation by means of oscillatory activity in the EEG.

Psychophysiological investigation of mental fatigue has a long tradition for it promises objective indicators of declining resources without the necessity to interfere with the primary task of the observed person (Lal and Craig, 2001; Papadelis et al., 2007). Most studies report an increase of spectral power in the lower frequency-bands (theta and alpha) with increasing time on task (Aeschbach et al., 1997; Craig et al., 2012; Lal and Craig, 2002; Torsvall and Akerstedt, 1987), whereas spectral power in the beta- and gamma-range decreases (Fan et al., 2015).

Ongoing frontal midline theta (FMθ) power increases with time on task (Gevins et al., 1997; Laukka et al., 1995; Smith et al., 1999) and

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http://dx.doi.org/10.1016/j.ijpsycho.2017.04.003
Received 21 December 2016; Received in revised form 17 March 2017; Accepted 7 April 2017
Available online 08 April 2017

prolonged wakefulness (Caldwell et al., 2003). It has been also found to be positively associated with task demands (Jensen and Tesche, 2002; Onton et al., 2005; Smith et al., 1999). Since an increase of FMθ power is not specific to a certain modality or a certain tasks, FMθ is often seen as a correlate of mental effort.

The pattern for alpha power is less consistent. While Cajochen et al. (1995) report a steady increase of alpha power with prolonged wakefulness, Strijkstra et al. (2003) found a strong negative correlation of alpha power and sleepiness. In a sleep deprivation study, Caldwell et al. (2002) reported increased alpha power with time on task in helicopter pilots during flight, but decreased alpha power in laboratory testing conditions. Here, the electrode site where alpha is measured plays an important role. While the results outlined above mostly refer to posterior sites, where alpha power reaches its maximum, relations of increasing alpha and time on task seems to be more reliable at frontal leads (Barwick et al., 2012; Fan et al., 2015; Wascher et al., 2014). Several studies also found an increase of beta power to be related to the occurrence of mental fatigue (Craig et al., 2012; Fan et al., 2015; Lal and Craig, 2002). Craig et al. (2012) argued that an increase of beta power at frontal recording sites may reflect an increase of cognitive effort.

Closely connected to the construct mental fatigue is the effect of breaks, as the investigation of the possibility to recover from task demands also allows for gaining insight into processes involved. For working environments it could be shown that breaks can reduce the risk for accidents in industry (Tucker et al., 2003) or improve productivity and job satisfaction (Dababneh et al., 2001). Until now, there are only few studies examining the effect of breaks on EEG measures. Lim et al. (2013) found a significant effect of breaks in terms of a decrease of power in the lower frequency bands, i.e. alpha and theta. Chen et al. (2010) found a higher gravity frequency, a measure of central tendency within a given frequency spectrum, at occipital leads after breaks compared to pre-break intervals. This increase in gravity frequency was accompanied by a decrease in response times and an increase in accuracy. In a driving simulator study, Phipps-Nelson et al. (2011) could not find significant effects of breaks on EEG power.

With increasing age, cognitive resources decline both with respect to velocity (Salthouse, 1996) and with respect to efficacy (Hasher et al., 1999). The frontal lobe hypothesis (West, 1996) attributes these deteriorations to age-related structural and physiological changes in the prefrontal cortex (PFC). It could be shown that in an aging brain the PFC is more affected by atrophy (Driscoll et al., 2009) and a loss of white matter integrity (Salat et al., 2005) than other brain regions. The functionality of the dopaminergic system has also found to be reduced with increasing age (Volkow et al., 2000; for a review see Cabeza and Dennis, 2012). Executive control processes are supposed to be mediated by PFC functioning. Accordingly, age-related declines in behavior are most prominent in tasks strongly involving executive control processes, like the inhibition of irrelevant information (Lustig et al., 2007) or the coordination of multiple tasks (Naveh-Benjamin et al., 2005).

Compared to the rich body of findings dealing with the effects of time on task and mental fatigue, the literature regarding the influence of aging on mental fatigue is quite sparse. Nevertheless, with respect to an aging workforce the investigation of this interconnection is of great practical relevance. In a study implementing a Go/Nogo paradigm Falkenstein et al. (2002) could not find time on task effects in behavior, neither in a group of younger, nor in a group of older participants. The study was part of a 4 h-long test battery with constantly changing tasks, of which a Go/Nogo task was presented in the first and in the last block. Older participants showed a significant reduced latency of the Go-P3 ERP-component in the later test block, which the authors interpreted as a correlate of learning and compensatory processes. Wascher and Getzmann (2014), on the other hand, did find a stronger influence of time on task on behavior in older compared to younger adults. In an inhibition of return task older participants needed more time to inhibit irrelevant information with increasing time on task, an effect not observable in younger adults. In a recent study Wascher et al. (2016) used a Simon task for investigating time on task effects in different age groups. No differentiated effects of time on task in response times could be found between the age groups. However, only younger participants showed a decline in accuracy in the later course of the experiment. Since the Simon task in this study was also embedded in a sequence of alternating tasks, like the task in Falkenstein et al. (2002), it may be that potential differences between the age groups with time on task were superimposed by effects of task switching.

The pattern of results described above outlines the lack of clarity of the findings with respect to the relationship of mental fatigue and aging up to now. In order to address this issue, we conducted the present study. The younger subjects' data reported in the present study bases on the same sample as the data reported in Möckel et al. (2015). In order to induce mental fatigue, participants performed a Simon task (Simon, 1969; Simon et al., 1981) for about 3 h. The experiment also comprised several breaks with different durations. In the Simon task, participants respond to lateralized presented stimuli, whereby the lateralized responses are mapped to stimulus identity, not to presentation side. The stimuli can either be displayed on the same side as the assigned response (corresponding trials) or on the opposite side (non-corresponding trials). Response times are usually slower in non-corresponding trials. The influence of the irrelevant spatial information in terms of the difference in response times between corresponding and non-corresponding trials is called Simon effect.

In order to investigate whether the older participants were differentially affected by mental fatigue compared to younger participants, we analyzed a broad range of potentially relevant parameters. Besides behavioral data, EEG oscillatory activity in the theta-, alpha- and beta-band as well as the gravity frequency have been evaluated. Additionally, we assessed subjective measures for fatigue and motivational states via self-report during experimental breaks. In accordance with recent findings, we hypothesized the impact of time on task to be enhanced in older participants compared to younger participants. In particular, we expected the decline in performance with increasing time on task to be stronger in the older age group. This should also be reflected by the self-report measures in terms of higher fatigue ratings. An increase of EEG spectral power estimates for the theta-, alpha-, and beta-range should mirror expected increases of mental fatigue.

2. Methods

2.1. Sample

The sample comprised 14 older adults with a mean age of 64 years (range 56 to 70; 6 female) and 13 younger adults with a mean age of 24 years (range 20 to 30; 8 female). The sample of younger subjects is identical to the sample of Möckel et al. (2015). The inclusion criteria with respect to age were 20 to 30 years for the younger and 55 to 70 years for the older age group. Additionally, all participants had to be right- handed, must not suffer from any psychiatric, neurologic, or sleeping disorders, had to be non-smokers, and got to have normal or corrected to normal vision. All inclusion criteria were assessed via a self-report questionnaire. The recruitment of the younger sample took place via an announcement in a facebook group of the institute. Older participants were recruited based on a register of former participants as well as by means of an announcement in a local newspaper. All participants took part in the study voluntarily and signed an informed written consent. The ethics committee of the Leibniz Research Centre for Working Environment and Human Factors Dortmund approved the study.

2.2. Procedure

In order to control for circadian effects, all participants had to arrive at 8:30 a.m. at the laboratory and were then tested directly after the