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Effect of mental fatigue caused by mobile 3D viewing on selective attention: An ERP study

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ABSTRACT

This study investigated behavioral responses to and auditory event-related potential (ERP) correlates of mental fatigue caused by mobile three-dimensional (3D) viewing. Twenty-six participants (14 women) performed a selective attention task in which they were asked to respond to the sounds presented at the attended side while ignoring sounds at the ignored side before and after mobile 3D viewing. Considering different individual susceptibilities to 3D, participants' subjective fatigue data were used to categorize them into two groups: fatigued and unfatigued. The amplitudes of d-ERP components were defined as differences in amplitudes between time-locked brain oscillations of the attended and ignored sounds, and these values were used to calculate the degree to which spatial selective attention was impaired by 3D mental fatigue. The fatigued group showed significantly longer response times after mobile 3D viewing compared to before the viewing. However, response accuracy did not significantly change between the two conditions, implying that the participants used a behavioral strategy to cope with their performance accuracy decrement by increasing their response times. No significant differences were observed for the unfatigued group. Analysis of covariance revealed group differences with significant and trends toward significant decreases in the d-P200 and d-late positive potential (LPP) amplitudes at the occipital electrodes of the fatigued and unfatigued groups. Our findings indicate that mentally fatigued participants did not effectively block out distractors in their information processing mechanism, providing support for the hypothesis that 3D mental fatigue impairs spatial selective attention and is characterized by changes in d-P200 and d-LPP amplitudes.

1. Introduction

Many studies have demonstrated that three-dimensional (3D) viewing can cause visual discomfort or fatigue (Lambooij et al., 2009; Lambooij et al., 2013; Lee and Song, 2012; Mun et al., 2012; Park et al., 2014; Zhang et al., 2013). To provide 3D viewers with safety guidelines, many researchers have attempted to identify the factors contributing to these undesirable effects and have reported different physiological mechanisms and major components that can adversely affect human health. Recent findings related to 3D visual and cognitive symptoms indicate that mobile 3D viewing can cause more severe symptoms compared with those caused by large-sized display viewing (Jumisko-Pyykk et al., 2008; Shibata et al., 2011). This is attributed to the fact that mobile 3D viewers can be easily exposed to undesirable situations in which they view 3D content while moving or lying down at a relatively short distance from the screen. Although the potential risk has been raised in some studies, little supporting evidence from studies using objective measures closely linked to a high level of cognitive control and cognitive load has been reported.

An accumulated cognitive load can develop after performing mentally demanding tasks over a long period, which results in mental fatigue. Faber et al. (2012) determined the effects of mental fatigue represented by accumulated cognitive load on selective attention and reported that selective attention was significantly affected by mental fatigue. Due to a top-down modulated neuronal gain mechanism, neurons involved in the processing of task-relevant information (i.e., attended stimuli) fire more strongly while attenuating the activity levels of other neurons occupied by task-irrelevant information (i.e., unattended stimuli) (Chica et al., 2013; Eason, 1981; Faber et al., 2012; Kim et al., 2007; Luck, 1995; Pollux et al., 2011). Mentally fatigued individuals often experience difficulty distinguishing between target-relevant and -irrelevant information, and these individuals are easily distracted and unable to effectively focus on relevant information (Boksem et al., 2005; Lorist et al., 2000; Lorist, 2008). When people become mentally fatigued, their ability to selectively block distracters (i.e., irrelevant information) gradually decreases with an increasing mental load, leading to deterioration in proper coupling of attention

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mechanisms to perform goal-directed tasks (Csatho et al., 2012; Erickson et al., 2009; Faber et al., 2012; Meijman, 1997).

The effect of mental fatigue on the top-down modulation of earlier and later sensory gain processing can be revealed by investigating changes in earlier and later event-related potential (ERP) components (Boksem et al., 2005; Kok, 1997; Mun et al., 2012). Boksem et al. (2005) reported that the N2b component was useful for evaluating mental fatigue, indicating that N2b amplitude for ignored stimuli became as large as that for attended stimuli as people became more mentally fatigued with increasing time spent on a task. The changes in the N2b amplitude, which were affected by mental fatigue, seemed to indirectly reflect reduced neural firing in networks from the anterior cingulate cortex (ACC) to the striate cortex. The N2b component is known as an indirect index reflecting the higher-order cognitive mechanism of selectively processing extraneous stimuli. Miller et al. (2011) also found that earlier and later component amplitudes (e.g., P2, P3, and late positive potential (LPP)) were reduced with increasing task difficulty. This result suggests that neural resources in the limited attentional capacity were primarily reduced due to the accumulated mental load and that the remaining resources available were only allocated for processing stimuli (Bonnefond et al., 2010). The mental fatigue modulation of earlier sensory processing also led to diminished neural activity for further processing of stimulus information in the higher-order cognitive processing characterized by decreased LPP amplitudes, including the P300 component (Miller et al., 2011).

Similar fatigue effects were observed in previous studies in which participants were subjected to cognitive tests before and after viewing 3D content (Li et al., 2008; Mun et al., 2012). In a study conducted by Mun et al. (2012), participants performed a spatial selective attention task in which they allocated their attention to relevant stimuli while ignoring irrelevant stimulus trains. Reduced attention resources, which are characterized by decreased LPP amplitudes, prolonged latencies, and reduced attend-to-ignore ratios of steady state visually evoked potentials (SSVEPs) obtained in the post-viewing condition relative to those characteristics in the pre-viewing condition, indicated that 3D fatigue might be a severe type of mental fatigue in individuals with high susceptibility to 3D-induced fatigue. Li et al. (2008) also argued that cognitive load might accumulate during 3D viewing, such that the P700 latency modulated by mental fatigue was prolonged after 3D viewing relative to 2D viewing condition. The delayed LPP component reflects impaired higher-order cognitive control function that regulates the allocation of neural resources for detecting important stimuli and for further processing salient visual information (Mun et al., 2012; Murata et al., 2005). According to the cognitive control theory, the major functions of the ACC and striatum to effectively execute goal-directed attention tasks may be impaired by mental fatigue, suggesting that there is a problem in sustaining proper dopaminergic transmission in the ACC and striatum, which contributes to impaired cognitive control (Lorist et al., 2005).

3D viewing can cause the mental fatigue depending on individual variances in 3D susceptibility (Kim et al., 2013; Lee et al., 2010; Lee and Song, 2012; Li et al., 2008; Mun et al., 2012). The mental fatigue effects caused by undesirable 3D viewing can be characterized by changes in the ERP components (i.e., P200, N2b, and LPP). A possible reason is that the information processing capacity of magnocellular neurons in the lateral geniculate nucleus and the dorsal cortical visual stream, which link the primary visual cortex to the posterior parietal lobe, may be overloaded by undesirable 3D information or by long-term 3D viewing. In fact, the perception of coarse 3D depth is closely tied with visual information processing in the dorsal stream and in magnocellular neurons (Livingstone and Hubel, 1987; Parker, 2007). For these reasons, we presented the mobile content to each participant with the maximum level of crossed disparity allowed by the device in an effort to elicit the mental fatigue effects and further investigate the effects that were more dependent on 3D viewing. Thus, changes in amplitudes of earlier and later ERP components might be expected due to 3D mental fatigue affecting top-down modulation of earlier sensory gain and later cognitive processing.

Although supporting evidence for 3D mental fatigue has emerged, few studies have investigated the effects of 3D viewing on the cognitive function of 3D-vulnerable individuals. Most previous studies have examined 3D fatigue from subjective and optometric perspectives (Lambooij et al., 2013; Lee and Song, 2012; Polonen et al., 2012; Shibata et al., 2011; Zhang et al., 2013). Our study for evaluating 3D mental fatigue is novel in the following aspects. Firstly, we explored the effects of mobile 3D viewing, which more people are frequently exposed to, on cognitive control function connected with a selective attention mechanism based on the properties of evoked potentials related to mental fatigue. Second, we employed auditory stimuli to exclude the possibility that complex visual stimuli used to measure mental fatigue might slightly contribute to the resulting fatigue effects and to investigate pure mental fatigue effects caused by mobile 3D viewing. Last but not least, we used natural auditory sounds to effectively measure the influences of mental fatigue on selective attention and to obtain reliable ERP signals depending on the fatigue effects. Strong electrocortical activity can be elicited by using natural environmental sound, and the fatigue effect can be more sensitively detected than when pure tone stimuli are used (Miller et al., 2011). It is general that sequences consisting of frequent standard stimuli (non-targets) and rare targets are used in oddball paradigms. ERP components are elicited by discriminating the target stimulus from the standard stimuli. However, according to previously reported findings, we replaced the standard stimuli with silence, a single-stimulus paradigm with random intervals that is more robust than the conventional oddball paradigm when assessing cognitive load (Allison and Polich, 2008; Pan et al., 2000; Wetter et al., 2004). Selective attentional resources in humans have a limited capacity, and people in a mentally fatigued state may not effectively perform dual tasks that impose a high mental load. In contrast to a previous investigation (Mun et al., 2012), the present study used a modified paradigm with a primary auditory selective attention task and a secondary working memory (WM) task. Within the limited capacity for selective attention resources, the neural circuit for executing the primary task might compete for reduced attentional resources due to 3D cognitive fatigue, with additional attention resources for the secondary task (Durantin et al., 2014).

Thus, the purpose of this study was to investigate auditory ERP correlates of mental fatigue caused by mobile 3D viewing. Considering the reduced capacity of the selective attention resources and the distractibility in the selective attention mechanism, we hypothesized that differences in the amplitudes between the attended and ignored side would be reduced if mental fatigue occurs for individuals who are susceptible to mobile 3D viewing. The basis of our hypothesis is that fewer attentional resources are available in a mentally fatigued state, which impairs the ability to block out distracters. That is, fatigued individuals seem to have few problems in processing task-relevant information, but their ability to block out irrelevant information is reduced (Faber et al., 2012). Thus, cognitive fatigue caused by undesirable mobile 3D viewing might impair the selective attention ability such that ERP amplitudes on the ignored side might be stronger with increasing mental fatigue, which is characterized by distractibility. As a result, the remaining attention resources might be more reduced or depleted when severely fatigued people perform dual tasks. This situation might result in deteriorated performance, which would clearly reveal impairment in attention due to mental fatigue, given the human attention system's limited capacity (Keil et al., 2007). In summary, we defined differences in the amplitude of each ERP component (i.e., P200, N2b, and LPP) between attention conditions (attended vs. ignored) as d-P200, d-N2b, and d-LPP amplitudes. The following hypotheses regarding changes in amplitudes of the specific d-ERP components were tested: For fatigued ones, d-P200, d-N2b, and d-LPP amplitudes after mobile 3D viewing would decrease compared to before the viewing.