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Does sleep quality affect involuntary attention switching system?

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Abstract

We studied the relationship between sleep quality and quantity and subsequently recorded automatically evoked event-related potential (ERP) responses. In previous studies decrement of attentional processing has been associated with changes in sleep. Sleep is shown to associate also with ERPs elicited by unattended sound stream, however, there is no consensus on these effects. A recent study suggested that the early anterior P3a to novel stimuli in attended stream is attenuated and the late parietal P3a is strengthened by total sleep deprivation. We carried out 72-h consecutive actigraphy measurements in a naturalistic setting to collect information about variation in sleep duration, sleep onset latency, sleep efficiency, and percentage of sleep. MMN and P3a deflections to infrequent changes in sound duration and pitch in unattended sound stream were obtained in a separate recording session from the same subjects when they were awake. No significant correlations were found between sleep and MMN parameters, indicating that MMN is resistant to normal variation in sleep. However, P3a to both pitch and duration changes correlated positively with sleep onset latency, and P3a to duration changes correlated negatively with sleep efficiency and percentage of sleep. The correlation was higher in the posterior scalp areas. Our results suggest that the involuntary attention switching system, reflected by the P3a is sensitized as a function of decreased sleep quality.

Keywords: Sleep; Actigraphy; Event-related potentials; Sensory memory; Involuntary attention switching

Event-related brain potentials (ERP) reflecting time-locked processes in the brain provide a means to distinguish sensory processes from cognitive ones and to study specifically their associations with sleep [19]. The most obvious consequence of sleepiness and fatigue is decreased attention [5,26]. One of the ERPs, namely the P3b deflection peaking at 300 ms from stimulus onset or later, is elicited by target stimuli in an attended stimulus stream. P3b is related to allocation of attention and it is strongly affected by sleep deprivation [17] and changes in arousal level [16], and it varies even diurnally [14]. Sleep is shown to associate also with ERPs elicited by unattended sound stream, however, there is no consensus on these effects.

Mismatch negativity (MMN) is an ERP response elicited by different types of occasional changes in an otherwise recurrent sound sequence irrespective of subjects'task or direction of their attention [19]. MMN is suggested to reflect automatic change-detection processes. Previous studies examining the effects of sleep on MMN have suggested that amplitude of MMN is slightly attenuated in sleep deprivation and when recording wake-sleep transition [22,25]. Certain studies indicate that the frontal-lobe MMN component [23] that is thought to reflect initiation of an automatic attention-switch, is more sensitive to sleepiness than the MMN component that originates from the auditory cortices [19] and reflects sensory-memory functions [18,25]. However, in general, MMN seems to be fairly insensitive to effects of sleep, in fact it is elicited even when the subject is asleep [2,20]. Specific effects of sleep on MMNs to differ-

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ent deviations in sounds have not been examined, although, for example change in frequency and change in duration of a tone possess different processing requirements to the auditory system.

P3a is a subsequent, positive-polarity response that is also evoked by deviant sounds in unattended sound sequences [1,4]. However, P3a is much larger when the sounds are attended [1]. P3a is suggested to reflect involuntary engagement of attention by a change or a novel sound in a sound stream [6,8]. As a consequence of the involuntary attention switching process generating the P3a, performance in a main task may be temporarily distracted by a change in a task-irrelevant auditory input [6].

Although the frontal MMN subcomponent and the P3a both appear to be related to attention switching, they have critical differences. While the frontal subcomponent of the MMN component seems to be associated with preattentive initiation of an attention switch, the P3a deflection is presumably associated with the resulting attention switching. The P3a also seems to reflect a more general process than the MMN since correspondent responses have been found in the auditory [15], somatosensory [28] and visual systems [11,12]. It is suggested that P3a to infrequent sound deviations is generated in the auditory cortex (early P3a deflection), and in the prefrontal and parietal cortices (late P3a deflection) [27]. Novel evidence indicates that areas related to top-down attentional control and to involuntary attention switch might be mainly separate [3].

Only a few studies have examined the effects of sleep on P3a [10,13,20]. Nilsen-Bohlman [20] and Harsh and colleagues [13] reported that amplitude of P3a is reduced (or more specifically P3a is replaced by N350) when recording wake-sleep transition. A recent study by Gosselin et al. suggested that novelty detection during total sleep deprivation recorded in an attended sound stream is compromised by frontal deactivation, which is possibly compensated by posterior brain areas [10].

The effects of sleep quality on sensory and cognitive processes are beyond the scope of traditional sleep deprivation and wake-sleep transition studies. Previous studies suggest that long-term changes in sleep affect more strongly on attention than short-term changes in duration of sleep [21,26]. Because sleep quality is more permanent indicator of sleep problems this might also indicate that sleep quality affects more strongly on attention than duration of sleep. However, it is not known how the quality of preceding sleep affects to automatic auditory processing in awake subjects. We therefore studied in a group of volunteer students whether sleep quality and quantity measured from a 3-night sleep period would be reflected in MMN and P3a responses.

Sixteen healthy normal-hearing volunteer subjects (aged 18–30 years, eight males) participated in the experiment. None of the subjects had a diagnosed sleep disorder. One subject was excluded due to an actigraph malfunction, thus, 15 subjects were included in the data analysis. The study was approved by the Ethical Committee of the Department of Psychology, University of Helsinki.

Sleep quantity and quality were measured with wrist-worn ambulatory activity monitors (Basic Mini Motionlogger, Ambulatory Monitoring Inc., NY, USA). The zero-crossing method (ZCM), which counts the number of times per epoch that the activity signal level crosses zero, was used to register the movement signal. The actigraphs were worn for 72 h nearly continuously; short breaks were permitted for actions that might harm the device. The subjects were instructed to sleep as they usually do. We did not give specific instructions about naps or night sleep. The subjects were asked to keep a log on exact bedtimes and waking times as well as on the time of monitor removal. A sleep diary was used for subjective evaluation of sleep.

Continuous electro-encephalogram (EEG) was recorded some time between 9 a.m. and 7 p.m. on the day following the last sleep-recorded night. Due to reasonably short activity recording, the circadian rhythms were not analyzed to control the time of the ERP recording. However, diurnal time has not been shown to have an effect on MMN, P3a or manifestation of sleep quality. It is also unlikely that recording time was associated with sleep quality in the present study. Ag/AgCl electrodes were attached to Fz, F3, F4, Cz, C3, C4, T3, T4, Pz, PT3, PT4, LM (left mastoid), and RM (right mastoid) locations of the 10–20 system (referenced to nose electrode). Eye-movements were recorded using two electrodes: one below and the other on the right side of the right eye. The EEG was recorded at a sampling rate of 250 Hz by using a Neuroscan recording system. During the recording, the subjects were comfortably seated inside the sound-attenuated and electrically shielded chamber. They were instructed to attend to a silent, subtitled movie and to ignore the simultaneously presented stimuli from the loudspeakers located on both sides of the monitor (distance of the loudspeakers from the subject's head was 90 cm).

The stimuli were presented as in an oddball paradigm, where a repetitive standard tone was occasionally replaced by a deviant tone. The standard tones were spectrally rich harmonical tones comprising of three sinusoidal partials with a base pitch of 230 Hz and harmonic partials of 460 and 690 Hz. They were 105 ms in duration, including 10 ms rise and fall times. Two different deviants, a change in tone duration to 190 ms and a change in tone pitch to 300 Hz (with partials of 600 and 900 Hz), were presented in the same stimulus sequence with probabilities of 5% each. The deviants were otherwise identical to standards. Sound intensity was 56 dB SPL at the subject's head. Stimuli were presented with a constant stimulus onset asynchrony of 700 ms in ca. 4.5-min blocks (400 sounds). This part of the experiment consisted of four blocks. In the same recording, data were acquired for another study (to be published elsewhere) using another paradigm. The order of blocks was randomized between subjects. In the blocks for the other study, the subjects were also asked to watch video and ignore the sounds. The duration of the whole experiment was approximately 45 min, plus breaks.