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Research report

Daytime vigilance in chronotypes: Diurnal variations and effects of behavioral sleep fragmentation

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Abstract

Vigilance levels of 12 morning types (M-types) and 12 evening types (E-types) were investigated after a baseline night, 2 nights of sleep fragmentation (5 min of forced awakening every half-hour) and a recovery night. Sleep timing was adjusted to the preferred sleep schedule of each subject. Daytime vigilance levels were assessed with test series including a scale of subjective alertness, a psychomotor vigilance task (PVT), a waking EEG recording, and a sleep latency test. Test series were administered every 4 h, beginning 1.5 h after wake time. On the baseline day, significant diurnal variations were found for each vigilance measure, except for the PVT. Diurnal variations were similar in M-types and E-types. Sleep fragmentation decreased vigilance levels on each measure, except the PVT. Effects of sleep fragmentation and recovery were similar in the two chronotypes. These results highlight the similarities in diurnal variations of vigilance in the two chronotypes when studied at their preferred sleep schedule. Results were also compared between chronotypes with extremely early or late circadian phases ("Extreme" subgroup) and between those with similar, intermediate circadian phases ("Intermediate" subgroup). Diurnal variations of subjective alertness and sleep latencies differed between "Extreme" chronotypes but were identical between "Intermediate" chronotypes. There were no major differences in the response to sleep fragmentation in any subgroup. Since phase angles differed by the same amount between chronotypes within each subgroup, the results suggest that a difference in phase angle cannot be the only source of the differences observed in diurnal variations between "Extreme" chronotypes.

Keywords: Morningness–eveningness; Alertness; Circadian rhythms; Individual differences; Sleep–wake schedule; Circadian phase; Sleep regulation; Phase angle

1. Introduction

A major source of interindividual variability in human circadian rhythms resides in morningness–eveningness: some individuals prefer to go to bed early and to wake up early (morning-types; M-types) whereas others go to bed late and wake up late (evening-types; E-types). M-types and E-types usually differ by approximately 2 h in both their sleep timing and circadian phase [3,4,16,25,26,28,35]. Differences in the dynamics of homeostatic sleep pressure have also been reported [29,39]. Since circadian and homeostatic processes are involved not only in sleep regulation but also in the regulation of alertness, performance and neurobehavioral functions [1,11,33,40], it can be expected that M-types and E-types also differ in the regulation of their levels of vigilance.

Diurnal variations in alertness and performance levels have been assessed many times in chronotypes. However, M-types and E-types were always tested at the same clock time, thereby forcing M-types to follow a later sleep–wake schedule – and E-types to follow an earlier one – than what they would spontaneously choose. As expected in such conditions, results showed that M-types had high levels of vigilance in the morning and low levels later during the day when compared to E-types [10,22,24,34–36,41]. To determine whether morningness–eveningness *per se* is associated with differences in diurnal variations of vigilance levels, participants need to be studied according to their preferential sleep–wake schedule.

It is not clear whether vigilance levels of M-types and E-types differ in response to increased sleep pressure. One study

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compared M-types and E-types after a 4-h sleep restriction and found no difference between the two chronotypes for subjective sleepiness or for daytime sleep propensity [41]. A questionnaire study showed no difference in subjective daytime sleepiness between M-types and E-types even if E-types were reporting a greater sleep debt during working days, suggesting the possibility that E-types were less sensitive than M-types to increased sleep pressure [38]. Finally, one study found that alertness levels decreased more in M-types than in E-types after an extension of time awake due to delayed bedtime [5]. However, in this case many parameters were modified simultaneously, including duration of time awake and sleep, and circadian phase of the sleep episode. To compare the response of vigilance levels to increased sleep pressure between M-types and E-types, it is necessary to use a procedure that modifies sleep pressure without changing the normal relationship between the sleep episode and the internal circadian phase.

We recently studied M-type and E-type subjects before, during, and after an increase in sleep pressure produced by 2 nights of behavioral sleep fragmentation. All subjects were sleeping according to their preferred sleep schedule and this sleep schedule was kept constant for the duration of the research protocol. Sleep analyses revealed a difference between M-types and E-types in markers of homeostatic sleep regulation. Compared to E-types, M-types showed a faster decay rate of slow-wave activity (SWA; 1–5 Hz) in the frontal derivation of the baseline sleep EEG [29], and a larger increase in SWA between baseline and recovery sleep after sleep fragmentation [31]. It is therefore possible that vigilance levels also respond differently in M-types than in E-types to increased homeostatic pressure caused by sleep fragmentation.

Our previous analyses revealed the presence of two subgroups in our volunteers [28]. The first subgroup included M-types and E-types with extremely early or late circadian phases ("Extreme" subgroup), as estimated with the salivary dim light melatonin onset (DLMO). The other subgroup included M-types and E-types with overlapping intermediate circadian phases ("Intermediate" subgroup). M-types and E-types of this "Intermediate" subgroup had chronotype scores [23] in the morning (59–69) or evening (28–37) range, respectively, and showed significant differences in their habitual sleep schedule (for details, see ref. [28]). However, they had similar DLMOs. Differences in the dynamics of homeostatic sleep pressure were significant only between M-types and E-types of this "Intermediate" subgroup [30,32]. If daytime vigilance levels were related to the dynamics of homeostatic response to increased sleep pressure, differences in vigilance levels in response to sleep fragmentation should also be specific to the "Intermediate" subgroup. Another interesting feature of these subgroups was that they differed in the interval between the DLMO and the habitual wake time (the "phase angle"): in the extreme subgroup, the phase angle was about 1.6 h *longer* in M-types than in E-types, whereas in the intermediate subgroup, the phase angle was 1.8 h *shorter* in M-types than in E-types. Therefore, these subgroups represent an interesting model to explore the influence of different phase angles of circadian wake propensity on the diurnal variation of vigilance levels.

In this report, we first examine diurnal variations in various measures of daytime vigilance in M-type and E-type individuals assessed when sleeping according to their preferred sleep–wake schedule. In this condition, variations in vigilance levels were expected to reflect the spontaneous levels of wakefulness associated to morningness–eveningness without interference from sleep restriction or from an imposed sleep schedule. We then present daytime vigilance levels in the two chronotypes in response to increased homeostatic sleep pressure produced with behavioral sleep fragmentation, before and after a night of recovery. Finally, vigilance results are compared between M-types and E-types having an intermediate phase position ("Intermediate" subgroup), and between M-types and E-types with an extremely early or late circadian phase ("Extreme" subgroup).

2. Methods

2.1. Subjects

M-type and E-type participants (19–34 years) were recruited using a French version of the Morningness–Eveningness Questionnaire (MEQ; Horne and Östberg [23]). Twenty-four subjects completed the study: 12 M-types (MEQ scores 59–71, mean 65.9 ± 1.1) and 12 E-types (MEQ scores 27–40, mean 32.7 ± 1.2). There were 6 women and 6 men in each group. Age was similar in the two groups (M-types: 24.7 ± 1.5 years; E-types: 23.4 ± 0.7 years). All subjects were in good physical and psychological health, and had no sleep complaint. Enrolled subjects had a regular sleep schedule with a habitual sleep duration between 7 and 9 h. A 24-h laboratory screening confirmed the absence of sleep and vigilance disorder by polysomnography and a multiple sleep latency test (MSLT). Inclusion criteria were: sleep efficiency higher than 85%, night sleep latency shorter than 30 min, apneas/hypopneas index and periodic leg movements index lower than $5\ h^{-1}$, and mean diurnal sleep latency longer than 7 min. Subjects had no night work experience in the past year and no transmeridian travel in the past 3 months. They were all non-smokers and reported not using drugs or medications, except oral contraceptives. Women not using hormonal contraception (3 M-types and 4 E-types) were studied during the follicular phase of their menstrual cycle. Each subject signed an informed consent form approved by the hospital ethics committee and received a financial compensation.

2.2. Procedures

Sleep schedules were determined according to each subject's preferred bedtime and wake time, using information from screening sleep diaries during free days, and preferred wake time and bedtime as reported in the MEQ. The final decision for the study sleep schedule was made after discussion with the subject to ensure that it was close to the schedule that he/she would spontaneously adopt. Bedtime and wake time were determined for a sleep duration of 8 h, similar to the habitual sleep duration reported by the two groups of subjects (7.8 ± 0.2 h for M-types and 8.0 ± 0.2 h in E-types [28]). On average, self-selected sleep schedules were 2.6 h earlier in M-types (23:08 to 07:08 h $\pm$ 11 min) than in E-types (01:45 to 09:45 h $\pm$ 17 min). Subjects were requested to follow their selected sleep schedule ($\pm$30 min) for 7 days prior to laboratory admission. Compliance was verified by sleep diaries and by 24-h ambulatory measures of activity and light exposure (Actiwatch-L, Mini-Mitter Co., Bend, OR).

After the week of ambulatory monitoring, subjects were admitted to the laboratory for 5 consecutive days and nights. Circadian phase was assessed by the onset of melatonin secretion (DLMO) determined in saliva samples and by the estimated minimum of core body temperature (T_{min}) recorded during a normal 24-h sleep–wake cycle. On average, circadian phase was earlier in M-types than in E-types (melatonin onset: 20:41 $\pm$ 27 min vs. 23:23 $\pm$ 25 min and temperature minimum: 04:17 $\pm$ 23 min vs. 06:17 $\pm$ 29 min, respectively). The interval between wake time and circadian phase (the "phase angle") was similar in M-types and E-types (interval with DLMO: 10.60 ± 0.4 h vs. 10.66 ± 0.4 h;