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Original Article

The effects of chronotype, sleep schedule and light/dark pattern exposures on circadian phase

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ABSTRACT

Background: Chronotype characterizes individual differences in sleep/wake rhythm timing, which can also impact light exposure patterns. The present study investigated whether early and late chronotypes respond differently to controlled advancing and delaying light exposure patterns while on a fixed, advanced sleep/wake schedule.
Methods: In a mixed design, 23 participants (11 late chronotypes and 12 early chronotypes) completed a 2-week, advanced sleep/wake protocol twice, once with an advancing light exposure pattern and once with a delaying light exposure pattern. In the advancing light exposure pattern, the participants received short-wavelength light in the morning and short-wavelength-restricting orange-tinted glasses in the evening. In the delaying light exposure pattern, participants received short-wavelength-restricting orange-tinted glasses in the morning and short-wavelength light in the evening. Light/dark exposures were measured with the Daysimeter. Salivary dim light melatonin onset (DLMO) was also measured.
Results: Compared to the baseline week, DLMO was significantly delayed after the delaying light intervention and significantly advanced after the advancing light intervention in both groups. There was no significant difference in how the two chronotype groups responded to the light intervention.
Conclusions: The present results demonstrate that circadian phase changes resulting from light interventions are consistent with those predicted by previously published phase response curves (PRCs) for both early and late chronotypes.

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1. Introduction

The circadian system regulates daily variations in performance, behavior, endocrine functions, and the timing of sleep. Chronotype is used to describe individual differences in the timing of the sleep/wake rhythm. Early chronotypes have earlier sleep times, an earlier peak in alertness, and an earlier minimum core body temperature than late types. Because of later bedtimes and fixed wake times due to social and work obligations, late chronotypes tend to accumulate more sleep debt over the course of the working week compared to early chronotypes [1]. In fact, it has been suggested that late chronotypes suffer from a chronic form of jet lag [2] because their sleep/wake schedules are not well aligned with their social schedules. This chronic jet lag, also known as "social jet lag," has been linked to an increased risk of obesity [3], depression [4], and cardiovascular disease [5].

Sleep is governed by the interaction between the homeostatic and the circadian systems. The homeostatic system increases sleep pressure as a nonlinear function of time awake. An increase in adenosine over the course of the day has been associated with an increase in sleep pressure [6]. The circadian system sends an alerting signal to the brain during daytime hours and a sleep signal during nighttime hours. In entrained people, the circadian and homeostatic systems work together to assure wakefulness during daytime and consolidated sleep at night. Studies have shown that adolescents and late chronotypes are slower to build up sleep pressure, even though they seem to dissipate sleep homeostasis similarly [7–9].

Light exposure on the retina determines the phase of the circadian system. Phase response curves (PRCs) can be used to characterize the magnitude and direction of light-induced phase adjustments of the master pacemaker. Light exposure in the early evening and first half of the night will delay the circadian phase, whereas light in the latest part of the night and in the morning hours will advance the timing of the pacemaker [10]. It has been hypothesized that similar light exposures in the phase advance and phase delay portions of the PRC might be differentially effective for early chronotypes and for late chronotypes, and their respective sleep/wake schedules may indirectly reflect this difference.

Sharkey et al. [11] studied two groups of young, late types, both of which were placed on a 1.5-h earlier sleep/wake schedule than their normal schedule; one group received 1 h of

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short-wavelength (blue) light within 15 min of waking while the other group was not exposed to the blue light in the morning. Personal light exposures were continuously monitored for all subjects throughout the study. Subjects in both groups exhibited similar circadian phase advances after 1 week on the advanced sleep/wake schedule. Because the total measured daily light exposures for both groups were not statistically different, the authors concluded that the daily environmental light exposures associated with the prescribed (earlier) sleep/wake schedule were sufficient to advance the circadian phase in young adults who would otherwise exhibit a delayed pattern, with or without a morning blue light intervention.

Appleman et al. [12] placed participants on a 1.5-h advanced sleep/wake schedule, with half receiving a light intervention designed to advance the circadian phase (short-wavelength light exposure from blue light-emitting diodes or LEDs in the morning *and* short-wavelength-restricting orange-tinted glasses in the evening) congruent with their advanced sleep schedule, while the other half received a delaying light intervention (short-wavelength-restricting orange-tinted glasses in the morning *and* short-wavelength light exposure from blue LEDs in the evening) incongruent with their advanced sleep schedule. Subjects who received the advancing light intervention advanced the circadian phase, while those who received the delaying light treatment delayed their circadian phase irrespective of their earlier sleep/wake schedule.

The present study was designed to extend from those by Sharkey et al. [11] and Appleman et al. [12] by investigating whether those with earlier sleep schedules (early chronotypes) and those with later sleep schedules (late chronotypes) respond differently to controlled advancing and delaying light exposure patterns while on a fixed, advanced sleep/wake schedule. Using a mixed experimental design, 23 participants (11 late chronotypes and 12 early chronotypes) completed a 2-week, advanced sleep/wake schedule protocol twice, once with an advancing light exposure pattern and once with a delaying light exposure pattern. For both sessions, following a baseline week, both groups were placed on a 1.5-h advanced sleep/wake schedule during the second, intervention week. We speculated that if the circadian phase, as measured by dim light melatonin onset (DLMO), were similar, but bedtimes were different between the early and late chronotypes, the controlled light schedules would fall at different parts of their PRCs, which, in turn, would lead to differential effects for the controlled advancing and delaying light patterns of the two groups [7–9,13,14]. Therefore, we hypothesized that for the controlled delaying light exposure pattern (light in the evening) the late chronotypes would receive the delaying light at a later circadian phase than the early types, resulting in greater phase delays for the late chronotypes than for the early chronotypes. For the controlled advancing light exposure pattern (light in the morning), the early chronotypes would receive the advancing light at an earlier circadian time than the late chronotypes, resulting in greater phase advances for the early chronotypes than for the late chronotypes.

2. Materials and methods

2.1. Participants

Twenty-four participants were recruited through website advertisement, word of mouth, and e-mail announcements. One subject dropped out of the experiment at the start of the intervention week because he could not comply with the advanced sleep/wake schedule. The results for the remaining 23 subjects who completed the entire experimental protocol are reported here. They were selected based on their self-reported chronotype, as described in the Munich Chronotype Questionnaire (MCTQ) [1]. In brief, the subjects were asked to rate themselves as extremely early type (0), moderate early type (1), slight early type (2), normal type (3), slight late type (4), moderate late type (5), and extreme late type (6). Those who rated themselves as extreme, moderate, and slight early chronotypes (MCTQ = 0–2; $n = 12$; Early Group) or moderate and extreme late chronotypes (MCTQ = 5–6; n = 11; Late Group) and also reported regular sleep patterns (ie, no diagnosed sleep disturbances) were accepted into the study. The mean ± standard deviation (SD) in chronotype score was 1.0 ± 0.6 in the Early Group and 5.4 ± 0.5 in the Late Group. Using the calculation procedure published in Roenneberg et al. [1], we also calculated chronotype scores using the corrected mid-sleep on free days with adjustments for sleep debt accumulated during the work week (MSF_{sc}) from baseline actigraph data. The average ± SD MSF_{sc} for the Early Group was 2.5 (0230) ± 0.3 and 5.5 (0530) ± 1.0 for the Late Group.

All participants reported that they had no major health concerns and that they did not take pharmaceuticals, except for women taking birth control pills. Participants (17 women) ranged in age from 18 to 51 years old (mean age ± SD, 31.1 ± 11.1). The participants' mean ± SD age was 40 ± 7.4 in the Early Group (nine females) and 21.5 ± 2.3 in the Late Group (eight females). Each participant selected for the study had to demonstrate an ability to use instant messaging and to respond quickly with his or her own personal mobile device to electronic prompts from the researcher. All participants were provided written informed consent approved by Rensselaer's Institutional Review Board and were paid for their participation in the study.

2.2. Study overview

Two 13-day sessions were employed in the present study. The protocol was the same as that employed by Appleman et al. [12], except that every subject in the present study experienced both an advancing and a delaying light intervention, as described below. In brief, every participant was asked to continuously wear a Daysimeter-D [15–17] on the wrist at all times, except when showering and swimming. During both baseline weeks (6 days each), participants wore the device while keeping their regular schedule. At the end of each baseline week, participants reported to the laboratory for collection of evening saliva samples used to assess DLMO. For the intervention weeks (7 days each) immediately following each baseline week, all participants were placed on an advanced sleep/wake schedule that was 1.5 h earlier than their regular sleep/wake schedule. Immediately following saliva collection after the first baseline week, subjects were randomly assigned to receive either the advancing or the delaying light intervention during the subsequent intervention week. At the end of this first intervention week, participants again reported to the laboratory for evening saliva sample collection to assess DLMO. After a 3-week washout period, subjects completed the second 13-day session; those who received the advancing light intervention first received the delaying light intervention second, and vice versa.

2.3. Home monitoring

Personal light/dark and activity/rest patterns were continuously monitored for each participant with a Daysimeter-D. The device was worn on the nondominant wrist at all times, except for swimming and showering, over the course of both 13-day sessions. Participants were asked to avoid covering the device with clothing.

Figueiro et al. [16,17] previously documented the physical and calibration characteristics of the Daysimeter-D. Briefly, light sensing by the Daysimeter-D is performed with an integrated circuit (IC) sensor array that includes optical filters for four measurement channels: red (R), green (G), blue (B), and infrared (IR). The R, G, B, and IR photoelements have peak spectral responses at 615, 530, 460, and 855 nm, respectively. The Daysimeter-D is calibrated in terms

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