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Influence of different light intensities during the day on the motor activity in adolescents

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Abstract. This study investigates the impact of varying light intensities throughout the day on motor activity levels in adolescent girls aged between 14-16, who are students at a boarding school. The study lasted for three weeks, with each week consisting of four days. During this period, participants experienced three different lighting conditions from 07:00 to 18:00. These conditions included: standard light intensity in real-life settings, wearing blue-blocking glasses, and spending at least 1.5 hours outdoors daily for natural light exposure. The aim was to understand how modern lighting sources can replace natural lighting and to assess the influence of the lighting spectrum on the daily rhythms of motor activity. Restriction of blue light led to an increase in the average daily level (MESOR) of the intensity of movements denoted by HPIM (High Proportional Integrative Measures), as well as a decrease in the amplitude of the circadian rhythm ZCM (Zero Crossing Mode). This confirms the important role of blue light during the daytime as a Zeitgeber of the circadian rhythm. When adolescents spent at least 1.5 hours outside, mostly in the afternoon, the acrophases of ZCM's 24-hour rhythm shifted half an hour later.

1 Introduction

The influence of environmental factors, particularly light, on human physiology and behavior has garnered significant attention in scientific research. Light serves as a powerful Zeitgeber, or timekeeper, regulating various biological processes, including the sleep-wake cycle and motor activity [1, 2]. Understanding the impact of different light intensities during the day on motor activity patterns in adolescents is crucial, as this population segment undergoes rapid physical and cognitive development, making them particularly susceptible to environmental influences.

Circadian rhythms, which are endogenous oscillations with a period of approximately 24 hours, regulate many biological functions, including sleep and activity patterns. Recent research has demonstrated the interplay between circadian rhythms, hemodynamics, and physical activity [3-5]. For example, Gumarova et al. [3] conducted a comparative analysis of circadian rhythms of hemodynamics and physical activity, highlighting the intricate

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relationship between these variables. Additionally, Wuerzner et al. [6] found that step count, as a measure of physical activity, was associated with lower nighttime systolic blood pressure, indicating a potential link between activity levels and cardiovascular health.

Investigations into the relationship between light exposure and motor activity have primarily focused on adults and clinical populations, with limited research targeting adolescents. However, evidence suggests that light can significantly influence activity levels in this demographic. For example, a study by Hysing et al. [7] found that exposure to natural light during the school day was associated with increased physical activity among children. Similarly, research by Carpenter et al. [8] demonstrated that variations in light exposure affect sleep and subsequent activity levels in adolescents.

Despite these insights, gaps remain in our understanding of how specific light intensities during the day impact on the motor activity of school children. Furthermore, existing studies often rely on subjective measures or fail to capture the dynamic nature of light exposure in naturalistic settings. Thus, there is a need for comprehensive investigations employing objective measures, such as wrist actigraphy, to assess motor activity in relation to varying light conditions [9].

This study aims to research the influence of different light intensities during the day on motor activity in adolescents. Using wrist actigraphy and leveraging advancements in light-sensing technology, we seek to provide insights into how environmental factors shape activity patterns in this vulnerable population. Ultimately, this research may inform strategies for designing healthier learning environments and promoting active lifestyles among schoolchildren.

2 Materials and Methods

2.1 Study participants

The volunteers in this study were twenty adolescent girls aged between 14 and 16 years (mean age: 15 years ±1.0 SD (standard deviation); mean body mass index: 20.17 ± 2.44 SD) who were in good physical health. They attended boarding school with a comprehensive focus on STEM education, similar daily routines, and adhered to regular patterns of sleep and wakefulness.

Prospective study participants completed questionnaires regarding their overall health status, sleep quality as assessed by the Pittsburgh Sleep Quality Index (PSQI), and sleep-wake patterns using the Munich Chronotype Questionnaire (MCTQ) [10]. Those participants demonstrated satisfactory sleep quality (PSQI score <5), and no extreme chronotype (MCTQ score between >3 and <6). The study protocol, screening questionnaires and consent documentation were approved by the local bioethics committee of Al-Farabi Kazakh National University (No. IRB-A639).

2.2 Physical activity recordings

Motor activity was assessed using wrist actigraphy (MicroMotion Logger, AMI, USA), with measurements recorded as Zero-Crossing Mode (ZCM) and High Proportional Integrative Measures (HPIM) to capture movement frequency and intensity, respectively [6]. Furthermore, the device assesses wrist temperature, light intensity, and sleep status (0 or 1, denoting awake or asleep, respectively), in addition to measuring movement frequency and intensity. All data were collected at one-minute intervals.

The study spanned three consecutive weeks, during which only four full (24-hour) days from each week taken into account. During this period, volunteers experienced three different lighting conditions from 07:00 to 18:00. Adolescent girls wore actigraphs for three weeks: the first week served as the control week, where the adolescent girls were exposed to their usual lighting conditions. In the second week, they wore blue-blocking glasses (UVEX Skyper SCT-Orange, Honeywell, USA), hereinafter referred to as BBL (blue-blocked lighting), to create dim-light conditions. During the last week, adolescents were required to spend at least 1.5 hours outside per day to experience natural light conditions.

2.3 Chronobiologic data analysis

Twenty-four-hour cycles were analyzed using cosinor (Action 4, AMI, USA). This report presents the main characteristics of the 24-hour cycles: MESOR (rhythm-adjusted mean), amplitude (half of the predictable change within a cycle), and acrophase (timing of peak values relative to local midnight) for each component. The quantitative data is depicted as the mean value ± standard deviation (SD). Paired T-tests were used to compute the P-value. Results for days with changed lighting conditions were compared with typical days for adolescents, representing their real-life settings. Rhythms were considered to be statistically significant when P-value from zero-amplitude (no rhythm) test was <0.05.

3 Results and Discussion

Throughout daylight hours, external light intensities can escalate to illuminances of up to 100,000 lux in direct sunlight at noon and 25,000 lux under full-day light conditions. Moreover, within enclosed spaces, light intensities are notably diminished, with standard office lighting typically hovering around ~500 lux, often even lower [11-12].

Through artificial manipulation of light exposure among adolescent girls, alterations in the daily patterns of physical activity were observed, as outlined in the accompanying Table 1. Notably, the imposition of constraints on blue light resulted in a notable rise in the average daily intensity of movements (HPIM) while concurrently diminishing the amplitude of the circadian rhythm (ZCM) pertaining to micromovements characteristic of sedentary behaviors among STEM students. This indicates a smoothing out and attenuation of the circadian rhythm, highlighting the significant influence of blue light as a zeitgeber in regulating diurnal activity patterns [13-16].

The investigation into the motor activity patterns of adolescent girls within a boarding school setting, after spending at least 1.5 hours outdoors, revealed a noteworthy delay in the acrophases by half an hour (ZCM), as illustrated in Table 1. Further examination of the daily illumination rhythms unveiled a shift from 13 hours 53 minutes ± 38 minutes to 14 hours 22 minutes ± 46 minutes, indicating a 29-minute delay. Consequently, the peak phase of daily motor activity coincided with the peak phase of daily light exposure among adolescents. This temporal delay is attributed to the adolescents' engagement in outdoor activities during their leisure time, predominantly in the afternoon. Moreover, there was a reduction in the amplitude of the 24-hour fine motor skills rhythm (ZCM), alongside an increase in the amplitude of HPIM and overall movement intensity, suggesting the positive impact of outdoor exposure on motor activity. Thus, despite advancements and alterations in the intensity and spectrum of modern artificial lighting, natural light, particularly the blue light spectrum, continues to exert a predominant influence.

A modest correlation in acrophase was observed between the Control and 1.5 hours outdoors conditions, as evaluated by ZCM ($r = 0.04$, $P < 0.05$). However, the acrophase of HPIM did not correlate significantly in either condition ($r = 0.07$, $P < 0.05$ between Control and BBL; $r = 0.193$, $P < 0.001$ between Control and 1.5 hours outdoors).

Table 1. Statistically significant 24-hour components in activity were found by Cosinor in 20 clinically healthy adolescent girls after four days of continuous data collection. ZCM (arbitrary units) and HPIM (arbitrary units) was collected at 1-minute intervals.

(mean ± SD)				**(mean ± SD)**		
Light conditions						
			h			h
BBL			h			h
1.5 hours outdoors			h			h

Note: P(T<=t) one-sided of t-test (compares the sets of measurements with the control): * p<0.05, ** p<0.005, *** p<0.001

While there was no significant correlation observed between the MESOR values of ZCM between Control and 1.5 hours outdoors (r = 0.0783, P < 0.05) and those between Control and blue-blocking light (BBL) conditions (r = 0.243, P < 0.001), a positive correlation was found between MESOR values of Control and BBL conditions with HPIM (r = 0.0373, P < 0.05).

Although amplitude was assessed by ZCM, showing correlations between Control and BBL conditions (r = 0.005, P < 0.005) and between Control and 1.5 hours outdoors conditions (r = 0.026, P < 0.05), the amplitude of movement under Control conditions showed significant alignment only with the 1.5 hours outdoors conditions based on HPIM (r = 0.05, P < 0.05).

The relatively consistent movement of the acrophases of motor activity amidst alterations in lighting conditions underscores the influence of social factors as the predominant zeitgeber in the context of a closed boarding school setting. These social factors, juxtaposed with the academic and recreational environment of adolescents, have been extensively documented in prior studies [17-19].

4 Conclusion

Based on the results obtained, both ZCM and HPIM demonstrated negligible alterations in MESOR in response to varying lighting conditions. However, the 24-hour cycle amplitude of motor activity intensity, as indicated by HPIM, exhibited an elevation in response to adolescents' augmented exposure to natural light. Additionally, a significant decrease in movement amplitude, denoted by ZCM, was evident, particularly notable when adolescents spent 1.5 hours in natural light.While no significant shifts were detected in the acrophases of motor activity circadian rhythms when adolescents wore blue-blocking glasses, a delayed shift of approximately thirty minutes was observed when adolescent girls spent 1.5 hours outdoors, specifically concerning ZCM.

The consistent movement of acrophases of motor activity against the background of changing lighting conditions emphasizes the influence of social factors as the predominant zeitgeber in the conditions of a closed boarding school.

In summary, circadian variations in motor activity contribute significantly to overall variance. Nonetheless, their fluctuations may be influenced not only by lighting conditions but also by various factors encompassing physical activity, dietary patterns, and physical as well as mental well-being.

Further investigations are warranted to delineate the precise dose-response relationships across diverse adolescents and to elucidate the temporal dynamics of potential synergistic effects arising from the concurrent application of physical activity, light exposure, and/or oral melatonin administration in modulating the phase alignment of the human circadian system. These inquiries are crucial for advancing our comprehension of the efficacy and practical applicability of physical activity as a therapeutic zeitgeber for the human circadian rhythm.

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