Sleep
Science

CASE REPORT

Circadian variations in the capacity to adjust behavior to environmental changes

Variações circadianas na capacidade de ajuste comportamental em face de alterações ambientais

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ABSTRACT

Background and objective: Circadian variations have been found in the performance of many human activities. The performance of many tasks depends on basic cognitive processes, such as executive functions. One of the components of these functions is the capacity to adjust behavior to environmental changes. The objective of this study was to identify circadian rhythms in the capacity to adjust behavior to environmental changes. **Methods:** Three college students were recorded in a constant routine protocol for 29 hours, starting at noon. Rectal temperature was measured every minute, and their performance on a tracking task was assessed every 1 hour and 40 minutes. In this task, each participant observed a circle following a linear path with a constant speed. Each time the circle appeared, the participant had to place a cursor inside the circle and press the left button of the mouse. After a variable number of circles, the path and speed were modified, and the participants' capacity to efficiently respond to these changes was measured. **Results:** All participants showed a decreased capacity to adjust their behavior to changes in the tracking task at night and early in the morning. **Conclusions:** Circadian variations were observed in people's capacity to adjust their behavior to changes in the tracking task. This capacity was reduced at night and early in the morning. This impairment might lead to errors and accidents in night-shift workers.

Keywords: Circadian rhythm; Environment; Human activities

RESUMO

Introdução e objetivo: Variações circadianas têm sido verificadas no desempenho de várias atividades humanas. A execução de muitas tarefas depende de processos cognitivos básicos, tal como a função executiva, sendo que um destes componentes é a capacidade de ajustar o comportamento em face de alterações encontradas no ambiente. O objetivo deste estudo foi identificar ritmos circadianos que influenciam a capacidade de se ajustar a tais alterações ambientais. **Métodos:** Três alunos de graduação se submeteram a um protocolo de rotina por 29 horas ao registro que deu início ao meio-dia. A temperatura retal foi medida a cada minuto e o desempenho em uma tarefa de rastreamento foi avaliado a cada 1 hora e 40 minutos. A tarefa executada por cada um dos participantes consistiu no acompanhamento de um círculo em trajetória linear a velocidade constante. Sempre que o círculo aparecia, o participante era requisitado a colocar o cursor dentro dele e clicar o botão da esquerda do mouse. Após um número variado de círculos, a trajetória e a velocidade foram alteradas e a capacidade dos participantes em responder a estas variações foram medidas. **Resultados:** Os três participantes apresentaram menor eficiência ao acompanhar o círculo durante a noite e pelas primeiras horas da manhã, demonstrando menor capacidade de ajuste comportamental nestes períodos. **Conclusão:** Variações circadianas foram verificadas na capacidade de ajuste comportamental na tarefa de acompanhamento do círculo. A redução desta capacidade ocorreu durante a noite e nas primeiras horas a manhã. Tal deficiência pode levar trabalhadores de turno noturno a sofrerem acidentes e cometerem erros.

Descritores: Ritmo circadiano; Meio ambiente; Atividades humanas

INTRODUCTION

Circadian rhythms have been found in human physiology as well as behavior. Circadian variations in human performance have been observed in many activities. For example, in the execution of sensory (1) and motor tasks (2,3), reaction time (4), a continuous performance task (5), memory tasks (6-8), reading comprehension (9), solving arithmetic problems (10), shifting criteria tasks (11), and in time estimation (12,13). Performance improves during daytime, reaching the highest level between 20 and 22h, while it declines at nighttime, reaching the lowest level between 4 and 6h (14,15).

Kleitman related physiological rhythms with rhythms in performance; he proposed that rhythms in metabolic activity (measured by body temperature) produce rhythms in performance (16,17). In this manner, metabolic oscillations can affect brain activity, modulating cognitive processes and, consequently, producing changes in performance.

Although evidence has been collected in support of Kleitman's hypothesis (4), there are several exceptions. Some cognitive processes have been shown circadian variations that are not synchronized with the circadian rhythm of body

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temperature (18). In the same way, other cognitive processes do not show circadian variations (10,19,20).

Kleitman's hypothesis assumes that oscillations in metabolism modulate performance in a general manner. However, it is possible that some brain areas are more susceptible to metabolic variations. This sensitivity could produce circadian variations in particular basic cognitive processes, which, in turn, would modulate the performance of many activities that depend on the use of that cognitive process. There are three basic cognitive processes that can modulate performance in many activities: attention, working memory, and executive functions (21,22). Therefore, it is relevant to assess potential circadian variations in these basic processes, with the purpose of determining which ones change in the course of the day.

Executive functions refer to the capacity to program, regulate, and verify behavior, and are crucial for problem-solving and self-control (23). Executive functions depend on the activity of the frontal cortex, specifically the prefrontal area (24,25). This study presents an analysis of one component of executive functions: the capacity to adjust behavior to the environment. This capacity is crucial to detect and correct errors during performance in order to adjust behavior to new environmental demands. Many activities that we carry out in daily life, such as driving a car, practicing sports, and handling tools or machinery, require the capacity to adjust our behavior to environmental changes in order to avoid errors that could cause accidents.

This study sought to identify circadian variations in people's capacity to adjust their behavior to environmental changes. In order to analyze potential circadian variations in this capacity, it is important to use a tracking task, which consists of following a stimulus that changes in position and speed (26).

In previous studies with tracking tasks, a decline in efficiency was observed at night and early in the morning, with an increase of efficiency in the afternoon (27-30). However, it is important to point out that these studies assessed the responses to each position of the stimulus, but not the capacity to adjust behavior to changes. In the present study, a tracking task was designed to present a stimulus with fixed path and velocity and, after a variable number of stimuli, introduce unpredictable changes in the direction and speed of the stimulus. This feature allowed us to register adjustments in people's behavior in response to each change in the environment. The objective of the study was to identify circadian rhythms in people's capacity to adjust their behavior to changes in the environment.

METHODS

Participants

Three college students volunteered to participate in this study: a 19-year-old male and two 17-year-old females, all right-handed, with no health or sleeping problems. The participants were not taking any medication that could affect the central nervous system during the study. All of them attended classes at a morning shift (7 to 13h10) and did not have programmed activities after class or on weekends. Each participant signed an informed consent letter, which was also signed by the parents of minors. The project was approved by an academic committee and carried out in compliance with the principles of the declaration of Helsinki for human research.

Materials

A personal computer was used to present the stimuli and record the responses; stimuli were displayed on a 14" (600 x 800 pixels) monitor, placed at 60 cm in front of the participants. A Steri-probe® 491B thermistor probe connected to a Mini-Logger 2000 (Philips® Respironics) was used to record the rectal temperature.

Tracking task

The tracking task consisted of a 50-pixel diameter circle following a linear path across the screen at a constant speed of displacement (with a fixed inter-stimulus interval). The circle was displayed on the screen for 180-m, while the inter-stimulus interval was set at a value randomly chosen from 200 to 730 m for each trial. Each time the circle appeared, the participants had to target a cursor inside it and press the left button on the mouse using the index finger of the right hand. After presenting 22 or 33 circles, the path and speed of displacement (inter-stimulus interval) were modified. Sixteen changes in path and speed of displacement were presented. This task lasted seven hours and two minutes. To determine the degree of adjustment made to the changes in the task, the accuracy (i.e., correct responses) and latency to respond to the first and fourth stimuli after a change in the trajectory were analyzed. In addition, the number of circles required to the adjustment to changes in path and speed of displacement was analyzed.

Procedure

At the beginning of the study, the participants answered a questionnaire requesting general information; a Spanish version of the morningness – eveningness scale (22,31), and a questionnaire about daily caloric intake on two different days, one during a weekday and other on the weekend. The participants also kept a sleep diary for two consecutive weeks. The three participants reported that they had not consumed alcoholic beverage or drugs, or smoked tobacco, for at least three days before the recording session. The participants were then trained in the tracking task. After the training, the participants were individually recorded in a constant routine protocol for 29 hours in a cubicle isolated from sunlight, external environmental noise and temperature. The data recording started at

12h and finished at 17h of the following day. In this protocol, the environmental temperature was kept constant (24±1ºC), as well as light exposure (5 lux maximum) and caloric intake. Feeding was provided after each task application and consisted of one portion of nutritional supplement or fruit juice and whole-wheat flour cookies proportional to 1/14 of the 75% of their average daily caloric intake. Additionally, body posture remained constant, as the participants remained reclined in an armchair (45° angle) for the entire study period, only standing up to go to the restroom when necessary. Moreover, participants remained awake and did not have access to clock time. Participant rectal temperature was recorded every minute using a thermistor probe inserted 10 cm in the rectum and connected to a minilogger. The tracking task was performed every 1 hour and 40 minutes, for a total of 18 applications. In addition to the tracking task, other tasks – not presented in the Results section of this study – were assessed during the study. Recording sessions were carried out on Tuesdays for participants 1 and 2, and on Thursday for participant 3.

Data analysis

Mean values of bedtime, waking time and sleep duration were calculated from the sleep diary. The median rectal temperature per hour was calculated for each participant. These data were smoothed with a three-point moving average, and a Cosinor analysis was applied to calculate the fitting percentage of the data to a 24-hour sinusoidal curve.

To obtain indices of behavioral adjustment to changes in the tracking task, the number of circles required to adjust (i.e., three consecutive correct responses) to the 16 changes of each task application were averaged. The accuracy (i.e., percent of correct responses) and the median response latency to the first and fourth circles after these changes of path were calculated. In addition, the moment of the day at which the maximum and minimum values were reached on these indicators was obtained for each participant.

RESULTS

The three participants were classified as intermediate on the morningnesss – eveningness scale (54, 47 and 53). Before the recording session, the participants slept an average of 7 hours and 24 minutes, 6 hours and 55 minutes, and 8 hours and 9 minutes per night, bedtimes were 01h54, 01h46, and 01h34; and waking times were 7h53, 8h07, and 8h39, respectively. The day before the recording session, the participants took 3 hours, 1 hour and 30 minutes and 1 hour naps during daytime and slept for 9 hours and 10 minutes, 6 hours and 50 minutes and 8 hours during nighttime.

The participants showed circadian variations in rectal temperature (Acrophases: 17h, 16h20, 19h50; %R: 75.94, 94.29, 92.98; p<0.001) (Figure 1A).

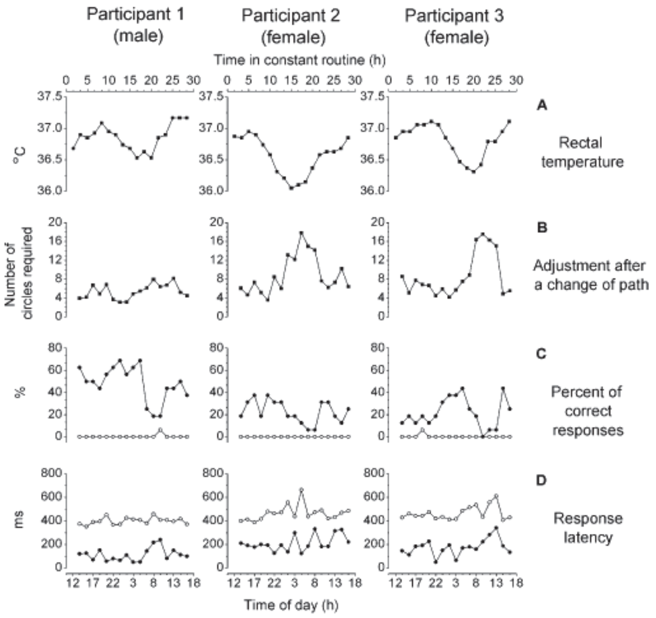

Figure 1: Rectal temperature and capacity to adjust behavior to environmental changes in a tracking task, for each participant during the recording session, in a constant routine protocol. (A) Changes in rectal temperature. (B) Number of stimuli required by the participants to successfully match the cursor with the circle in the place where the circle appeared after a trajectory change. In (C) and (D), the white circles represent the accuracy and latency to respond to the first stimulus after a change in path and speed, while the black circles represent the accuracy and latency to respond to the fourth circle after the change. The three participants showed a higher capacity to adjust to environmental changes in the afternoon, with lower capacity at night and early in the morning.

In the afternoon, the participants required, on average, 3.06, 3.56, and 4.5 circles to adjust after a change. However, during the night and early morning, the participants required more circles (averages of 7.94, 17.81 and 17.56 circles) to adjust after a change (Figure 1B).

The accuracy with which participants responded to the first circle after a change in trajectory was 0% for the three participants at all times of day, with response latencies between 350 and 650 m (Figures 1C and 1D). Participants demonstrated a good adjustment to the fourth circle in the afternoon, showing higher accuracy (68.75, 37.5, and 43.73% correct responses) and faster response latency (56, 126 and 48 ms) at this time of day. Worse adjustment to the fourth circle was observed at night and in the early morning, when participants showed decreased accuracy (18.75, 6.25, and 0% correct responses) and slow response latency (239, 331.5, and 240.5 ms) (Figures 1C and 1D).

DISCUSSION

This study presents a specific analysis of people's capacity to adjust behavior to environmental changes. These findings are consistent with the results of previous studies that analyzed efficiency to respond to tracking tasks (27-30). So, capacity to adjust to changes shows circadian variations, with higher efficiency in the afternoon and lower efficiency at night and early in the morning.

Some individual differences were observed. Participant 1 showed higher accuracy as well as lower response latency across the entire session when compared to participants 2 and 3. However, all of them showed circadian variations within their own execution level.

The constant routine protocol used in this study allows the detection of circadian rhythms by controlling factors that may affect these rhythms (32). This protocol involves sleep deprivation, which could potentially result in diminished performance over time. Nevertheless, the time of day at which the participants showed the lowest capacity to adjust to changes was at night and early morning, not at the very end of the session. These results are consistent with previous studies showing that both sleep deprived and non-sleep deprived participants presented a decline in efficiency in execution of a tracking task at these times of day (28,29).

Only three participants were included in this study, thus it will be necessary to replicate these data with a larger group. However, circadian variations were observed in each participant, so it is reasonable to expect that similar patterns would emerge from data recorded from other people. The individual pattern is crucial when circadian rhythms are analyzed (33). The participants were adolescents and, although a delay in the phase of the sleep-wake cycle were observed for this age group (34), the period of the circadian rhythms is similar to that of adults (35). Therefore, it is likely that the rhythms observed in this study are also present in adults.

The capacity to adjust to changes is a component of executive functions that depends on the activity of the frontal lobe, suggesting that this brain region is sensitive to changes in body metabolism. In consequence, according to Kleitman's hypothesis (17), metabolic circadian rhythms could influence the frontal lobe, altering executive functions and consequently affecting the performance of most human activities. In addition, circadian variations have been found in other basic processes: such as components of attention (22) and phonological and spatial components of work memory (8). Future studies should analyze interactions between these processes, their daily cycles, and their relationships with body metabolism. This type of information will provide a better understanding of the role of the biological clock in human behavior (36).

The capacity to adjust to environmental changes is crucial to verify and correct our actions. Impairment of this function can make people more likely to make mistakes and less able to correct them with the accuracy and speed required, leading to dangerous situations or serious accidents. This is an important risk factor for workers during night shifts, especially when engaging in activities that involve handling heavy machinery, driving vehicles, or other operations that are carried out in variable conditions and require quick and precise responses.

The decline observed in the capacity to adjust to environmental changes corresponds with a higher incidence of errors and lower efficiency of workers during night and early morning hours. The error rate and low efficiency of workers at night and dawn can also be linked to a higher frequency of accidents during night shifts. Moreover, these accidents are often more serious than those that happen during day shifts (37).

In conclusion, circadian variations were observed in the capacity to adjust behavior to environmental changes in a tracking task. A decline in this capacity was found at night and early in the morning. This decline might be a risk factor promoting more errors and accidents for people working at a night shift or early in the morning.

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