REVIEW ARTICLE

Adv Psychiatry Neurol 2023; 32 (3): 162–166
DOI: https://doi.org/10.5114/ppn.2023.132032

ADVANCES IN PSYCHIATRY & NEUROLOGY
POSTĘPY Psychiatrii i Neurologii

Time of day and chronotype in the assessment of cognitive functions

Monika Wiłkość-Dębczyńska, Magdalena Liberacka-Dwojak

Institute of Psychology, Kazimierz Wielki University, Bydgoszcz, Poland

Correspondence to:
Dr. Monika Wiłkość-Dębczyńska
Institute of Psychology
Kazimierz Wielki University
1 Leopolda Staffa St.
85-867 Bydgoszcz, Poland
e-mail: monikawilkosc@gmail.com

Submitted: 27.04.2023
Accepted: 02.07.2023

Publication from the "Integralia 2022" conference, Warszawa–Łódź 25.11.2022

Abstract

Purpose: Circadian rhythms are synchronized, through the endogenous biological clock, with the 24-hour cycle, and associated with numerous changes in human functioning, both in physical and mental aspects. It is assumed that daily fluctuations in cognitive performance are a consequence of interacting homeostatic and circadian processes regulating an individual's sleep-wake rhythms. A chronotype may be understood as a phenotype of circadian cycles determined by an endogenous biological clock. Despite research findings showing a significant relationship between those factors and cognition, they remain insufficiently considered in the domain of cognitive psychology and neuropsychology.

Views: This narrative review aims to describe and highlight the interactions between the time of day, chronotype, and cognitive performance in domains of mental activity variables, receptive functions, memory and learning, expressive functions, and thinking.

Conclusions: The results of the research show that time-of-day effects on basic and more complex cognitive functions depend on an individual's chronotype with a dominant effect of synchrony between chronotype and time of cognitive testing, with large differences in circadian cycles between younger and older age groups. It is suggested that chronotype assessment and time of day control should be included as important variables in the diagnosis of cognitive function in both healthy and clinical populations. There is also an emerging need for further investigations to better understand how chronotype and circadian rhythms modulate human brain physiology and cognition.

Key words: cognition, chronotype, time of day.

INTRODUCTION

Biological rhythms are repetitive biophysical, biochemical, and behavioral changes occurring as a response to environmental factors, including the Earth's revolution and rotation, and also tides [1, 2]. There are several types of biological rhythm, according to their duration, such as the ultradian with an oscillation period of fewer than 20 hours (e.g. heartbeat or breathing rhythms), the circadian with an oscillation period of about 24 hours (e.g. the sleep-wake cycle), and infradian, with an oscillation period of more than 28 hours (e.g. the menstrual cycle) [2]. However, the most studied of these are the circadian rhythms, which are generated by the endogenous biological clock; this is an internal oscillator of gene-controlled biochemical processes taking place in the cells and tissues of the body, enabling the continuous measurement of time and the synchronization of life processes of organisms in the context of cyclical changes in external environmental conditions [3].

Physiological processes influenced by circadian changes include core body temperature, diuresis, heart rate, blood pressure, hormone activity, immune response, and pain sensitivity [4, 5]. Circadian changes can also lead to the aggravation of a number of medical conditions, such as coronary heart disease, hypertension, bronchial asthma, osteoarthritis, and depressive disorders [2, 6, 7]. Several studies have proved that the disruption of circadian rhythm might lead to metabolic diseases, obesity, cancer, neurodegenerative disease, and increased risk of cardiovascular diseases and stroke [1, 3].

Circadian rhythms in mental functioning are observed in cognitive and emotional areas, with a common example being the activation of changes closely related to the sleep-wake cycle [8]. Recent research has revealed that the level of activation, also referred to as the level of arousal, psychophysical drive, vigilance, and sensitivity to stimuli, gradually rises throughout the day and peaks in the late afternoon after a brief period of decline in the early afternoon [2, 8]. Inter-individual differences in timing can be observed between those who engage in activity early in the day and those who do so later in the day. The individual preference for a morning-to-evening circadian activity cycle is referred to as one of the manifestations of the chronotype in humans. It is closely related to the parameters of the sleep-wake course, such as the duration of sleep, the time of falling asleep and the time of waking up, and the midpoint of sleep. Individual differences in the sleep-wake cycle are proven to be one of the most relevant indicators of chronotype [1]. Chronotype can therefore be understood as a phenotype of circadian cycles determined by an endogenous biological clock. Individuals can be classified as having a morning/early, evening/late, or neutral/intermediate chronotype [9]. The aim of this narrative review was to characterize the relation between chronotype, time of day and cognitive functioning.

IMPACT OF TIME OF DAY ON COGNITIVE FUNCTIONS

It is assumed that daily fluctuations in cognitive performance are a consequence of interacting homeostatic and circadian processes regulating an individual's sleep-wake rhythm. An increase in the homeostatic need for sleep is related to cognitive deterioration. Due to the circadian processes this relationship is not linear, as the interactions involved are aimed at strengthening and sustaining wakefulness and mental activation, especially in the evening when the need for sleep is the strongest [10].

Over a century ago, Ebbinghaus proved that the learning of meaningless syllables proceeds more efficiently in the morning than in the evening. Kraepelin, in his research carried out in the 1920s involving the memorization of adding a series of digits in memory, observed a fluctuation in cognitive performance during the day [2]. Kleitman's [11] research on the observation of the variability of cognitive functions' when it came to the circadian regulation of body temperature proved the relationship between an increase in body temperature and psychomotor speed, up to the acrophase of the temperature rhythm that is associated with the fastest reaction time in simple cognitive tasks.

Attention components are known to show homeostatic and circadian fluctuations in alertness and selective and sustained attention. They improve during the day, with higher levels in the afternoon and evening hours. Circadian rhythm itself is associated during the night and in the early morning with an increased risk of errors, though this can depend on chronotype [12]. Interestingly, a time-of-day effect is important also for prospective memory, irrespective of chronotype [12, 13]. The strength of the relation between time of the day and cognitive performance increaseswith age. The level of cognitive functioning in older adults is significantly worse at a non-optimal time of day [14].

EFFECT OF CHRONOTYPE ON COGNITIVE FUNCTIONING

The relationship between chronotype and cognition is influenced by many factors, such as age, task difficulty, and duration of the task, duration the period of wakefulness, testing method used, and length, quality, and degree of sleep inertia, which is defined as a physiological process that occurs immediately after awakening and is characterized by a reduced level of activation and increased disorientation. The basic rest-activity cycle with a 90-minute fluctuation in alertness is also relevant to cognitive performance [2, 15].

The latest research indicate that chronotype is strongly related to cognitive functioning, with better performance at the individual's preferred time of the day [16]. People with an evening chronotype cope better with the increasing need for sleep, which allows them to maintain cognitive performance in the evening, whereas in people with a morning chronotype it deteriorates compared to their morning capabilities [14]. Lezak *et al.* [17] categorize cognitive functioning in four basic groups: receptive functions, memory and learning, thinking, and expressive functions. They also distinguish the mental activity variables responsible for maintaining the readiness of the cognitive system. Within each of these domains, more elementary cognitive functions can be defined [17].

Chronotype and mental activity variables

The mental activity variables consist of consciousness level, attention, and activity rate [17]. It has been proved that mental activity is strongly related to the chronotype. In individuals with the morning type, maximum activation occurs approximately three hours earlier than in those with the evening type. Individuals with the extreme evening chronotype rate their mental activity lowest at 8 am, while its value is higher for the other chronotypes, reaching the highest rating in those with the extreme morning chronotype. The measurement at 11 pm showed an inverse relationship [2, 18, 19]. Pavlenka *et al.* [20] analyzed the changes in external respiration parameters and heart rate variability due to mental activity in students with different chronotypes. It was shown that participants with an intermediate chronotype performed best in the conditions of monotonous mental activities in hours that did not coincide with their chronotypes, while morning-type individuals obtained the lowest results.

Attention seems also affected by circadian rhythm. Martínez-Pérez *et al*. [21] showed that chronotype determined vigilant attention more decisively in the evening than in morning chronotypes. In another study, selective attention was better in morning chronotype than in evening chronotype adolescents at 7 am, and significantly improved for both groups at noon and 2 pm, when all participants scored the same, whereas at 7:30 pm selective attention was better in evening type individuals [22]. Similarly, Venkat *et al*. [23] proved that attention and alertness were better during the individual's optimal time of day. Interestingly, the study of the effect of chronotype and sustained attention during a single night shift [24] found no significant effects of chronotype. These results suggest that under controlled sleep conditions, chronotype does not affect nighttime performance, which is more influenced by the amount and/or timing of sleep prior to night shifts than by circadian timing.

Chronotype and receptive functions

Receptive functions relate to perceiving, identifying, and interpreting sensory inputs [17]. Simple visual recognition tests are commonly used to study chronotype and receptive functions. The speed of task performance reflects the course of the body's temperature rhythm, with peak performance in the late afternoon and gradually decreasing accuracy throughout the day. Increasing the difficulty of the task shifts the optimal level of performance to the morning hours [2, 25].

Chronotype, memory and learning

Memory enables the encoding and storing of experiences from the past, the learning of new ones, and using them in the present and the future. Learning is the process of initiating constant changes in behavior on the basis of the plasticity of the nervous system [17]. Studies have shown a different relationship between chronotype and performance on memory tasks, depending on the type and process of memory.

Zarch *et al*. [26], in a study investigating chronotype orientation on daily and weekly rhythm fluctuations in working memory performance in preschool children, showed that it varied on different days of the week and at different times of the day. The research on evening chronotype students with ADHD showed no significant difference in the morning and evening measurements of working memory performance, even though the children made more errors in the morning than in the evening [27]. Similarly, Bennett *et al*. [28], in a study of short-term verbal memory and working memory found no differences between chronotypes in the morning and afternoon.

On the other hand, studies of semantic memory have shown a synchrony effect, indicating better performance at optimal times of the day according to chronotype. Older adults with the morning chronotype performed better on verbal memory tasks in the morning, while younger participants with the evening chronotype performed better in the afternoon. Importantly, the older individuals (60-75 years) performed as well as the younger ones (18-24 years) in the morning, whereas the younger adults performed 35% better than the older ones in the afternoon. This suggests an increasing relationship with age between better performance on cognitive tasks and the optimal time of day for the chronotype, regardless of the type of task [28]. In contrast, the opposite effect has been observed for non-declarative (implicit) memory. The better performance occurred at suboptimal times for both chronotypes and age groups [29]. These results suggest that declarative (explicit) memory processes, which require high cognitive control, are most efficient at times when mental activation and efficiency of attention are highest, whereas implicit memory is best at suboptimal times when attentional control is low and automatic processes are uninhibited. However, long-term memory training was shown to be more effective in the afternoon regardless of chronotype [30].

Balcı and Çalışkan [31] conducted a study on the learning styles of undergraduate students. The results showed that participants' preferences for visual and auditory learning styles differed by chronotype, with the visual style being more dominant in morning types and the auditory style in evening types. No relationship was found between chronotype and academic performance.

Chronotype and expressive functions

Expressive functions include speaking, drawing, writing, manipulating objects, gestures, and facial expressions [17]. Previous research has focused mainly on the influence of the time of day and language processes. The processing of a read text in the morning is more superficial, being based on word memory, while in the afternoon it is based on the meaning of the content and the message. The best understanding of verbal material was observed around 7 pm [2]. Rosenberg *et al*. [33] found that basic language processes are associated with chronotype-specific neuronal mechanisms. They observed that participants with morning chronotype exhibited attenuated fMRI BOLD responses in several language-related brain areas, and exhibited slower reaction times than those with evening chronotype. In addition, the evening chronotypes showed increased BOLD responses in task-related areas compared to the intermediate chronotypes.

Chronotype and thinking

Thinking relates to mental operations carried out on explicit or non-explicit information, with the following mental operations: computation, reasoning and judgment, concept formation, abstracting, generalization, ordering, organizing, planning, and problem-solving [17]. It is claimed that the evening chronotype is associated with the right-hemisphere style of thinking, e.g. that which is intuitive, holistic, synthetic, and visual-motor, and the morning chronotype with the left-hemisphere style, e.g. analytical, sequential, and verbal-abstract representations [34]. Furthermore, more stereotypical, automatic, and more easily accessible judgments appear at a time non-optimal for the chronotype [35]. Singh [36] in his study observed that creativity in performance was correlated with chronotype, with the morning type achieving better results. Oppositely, Simor and Polner [37] showed that chronotype was not associated with creative performance, but that there was a relation between late chronotypes and convergent thinking tasks. Evening chronotype participants who completed a test at non-optimal times showed better performance than morning ones. Giampietro and Cavallera [38] reported a relationship between eveningness and visual divergent thinking. Still, results regarding chronotype and thinking remain unclear [37].

CONCLUSIONS

Despite many years of research, it seems that insufficient attention is still paid to daily fluctuations in cognitive performance, depending on the time of day and chronotype, in the context of both scientific research and clinical practice [2]. These should also be taken into account when planning for the optimal functioning of an individual, especially in areas where cognitive efficacy is crucial, i.e., learning and working hours.

The results of this research show the dominant effect of synchrony between chronotype and time of cognitive performance, with large differences in circadian cycles between younger and older age groups [40]. Failure to take these variables into account when assessing cognitive functions may lead to erroneous conclusions. There is also an emerging need for further investigations to better understand how chronotype and circadian rhythms modulate human brain physiology and cognition.

Conflict of interest

Absent.

Financial support

Absent.

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