RESEARCH PAPER

Chronotype and Cognitive Performance: The Role of Time of Day and Circadian Synchrony

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Abstract
Chronotype is the individual difference in the preferred timing of sleep, wakefulness and daily activity and is typically described as a continuum from morningness to eveningness. These differences are tightly linked to the circadian timing system, which is linked to homeostatic sleep pressure and influences alertness and cognitive function throughout the 24-hour day. Cognitive performance is not uniform across the day, and attention, vigilance, processing speed, memory, executive function and decision making can fluctuate as a function of circadian phase, sleep history, age, task characteristics, and chronotype. The synchrony effect is suggested by evidence that cognitive performance is improved when a task is performed at a time that matches the individual's preferred biological timing. People who are morning types may do better in the morning, while evening types may do better in the evening. But cognitive performance is not consistently predicted by chronotype, and recent studies highlight the importance of chronotype x time of day interactions.
Discrepancy between biological and social timing can be exacerbated by modern social schedules, artificial light exposure, sleep restriction, and shift work. This mismatch of the circadian rhythm is known as social jetlag or circadian misalignment, which could lead to sleep debt and changes in cognitive function. This mini-review provides an overview of the available data on chronotype and cognitive functioning, focusing on diurnal variation, attention, reaction time, memory, executive functions, circadian synchrony, social jetlag and shift work.

Keywords: Chronotype; Cognitive performance; Circadian rhythm; Time of day; Synchrony effect; Social jetlag; Circadian misalignment
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1. Introduction

The physiological and behavioural functions of humans show rhythmic variations over a period of about 24 hours. Circadian rhythms control sleep-wake cycles, hormonal release, body temperature, metabolism, alertness and some aspects of cognition. These rhythms are endogenous (self-generated) and are entrained by environmental time cues, especially the light-dark cycle. The circadian system and the homeostatic regulation of sleep interact, leading to changes in alertness and performance throughout the day (Dijk et al., 1992; Wyatt et al., 1999; Carrier & Monk, 2000; Schmidt et al., 2007).

The timing of sleep and activity is referred to as chronotype. There are three types of chronotypes: morningness, eveningness, and those who fall somewhere in between. Morning types sleep and get up earlier, while evening types sleep and get up later (Horne & Östberg, 1976; Roenneberg et al., 2003; Adan et al., 2012). Biological, genetic, developmental and environmental factors such as age, sex, light exposure and social schedules (Baehr et al., 2000; Adan et al., 2012; Roenneberg et al., 2019) are all factors that influence chronotype.

Temporal variation is also seen in cognitive performance. Daily variations in attention, vigilance, memory, reaction time and executive functioning (Carrier & Monk, 2000; Schmidt et al., 2007; Gaggioni et al., 2014) have been found. Importantly, the optimal time for cognitive functioning may vary among people based on their chronotype. This has resulted in growing interest in the synchrony effect, which refers to improved cognitive functioning when the timing of assessment matches the person's biological preference (Taillard et al., 2021; May et al., 2023).

2. Chronotype and Its Biological Basis

Chronotype is a measure of the variability of the circadian and sleep-wake processes. One of the most popular subjective chronotype questionnaires is the Morningness-Eveningness Questionnaire (MEQ) developed by Horne and Östberg (1976). The Munich ChronoType Questionnaire (MCTQ) was then used to offer a behavioural approach using sleep timing on workdays and free days (Roenneberg et al., 2003). The MCTQ and MEQ measure similar but different aspects of circadian preference, and have been studied for their validity and psychometric properties (Zavada et al., 2005; Di Milia et al., 2013).

Physiological circadian phase differences are related to chronotype. The phase of the circadian temperature minimum is earlier in individuals with a more morning-oriented type and later in those more evening oriented (Baehr et al., 2000). Chronotype also varies throughout the lifespan, with more eveningness being reported during adolescence and early adulthood, and a gradual shift

toward morningness as age increases (Roenneberg et al., 2007; Adan et al., 2012).

Environmental light is an important regulator of circadian timing. Natural light is a strong environmental signal, and exposure to artificial light and electronic devices may affect circadian phase and sleep timing (Roenneberg et al., 2003; Gaggioni et al., 2014; Chellappa et al., 2011). So, chronotype is not a fixed behaviour, but rather a combination of biological factors and environmental timing.

3. Circadian Rhythms and Diurnal Variation in Cognitive Performance

The circadian system and homeostatic sleep pressure interact to regulate cognitive performance. The homeostatic drive for sleep builds up over time during prolonged wakefulness, and the circadian system gives a rhythmic drive for wakefulness. These two processes are linked to create typical daily fluctuations in cognitive functioning (Dijk et al., 1992; Wyatt et al., 1999).

Experimental research has shown that circadian phase affects alertness and cognition in addition to the amount of wakefulness. Under controlled conditions, the changes in alertness and performance follow those of physiological markers like core body temperature (Dijk et al., 1992; Wright et al., 2002). The results of this study offer a physiological explanation for the differences in performance between morning, afternoon, evening and night.

The Schmidt et al. (2007) review showed that time-of-day effects are present in a variety of cognitive domains, such as attention, executive functioning, and memory. Likewise, Wiłkość-Dębczyńska and Liberacka-Dwojak (2023) highlighted that the daily fluctuations in cognition are driven by the interplay between homeostatic and circadian mechanisms and that they are affected by chronotype. Thus, cognitive testing at various times of the day can yield varying results within the same person.

4. Chronotype and Cognitive Performance

4.1 Attention and vigilance

Cognitive functions most closely associated with circadian timing are attention and vigilance. Matchock and Mordkoff (2009) studied the alerting, orienting, and executive aspects of attention at various times of day and found that chronotype and testing time can affect attentional performance.

Evening chronotypes also show poorer performance in the morning while morning types show relatively better performance in the morning, according to research. Facer-Childs et al. (2018) found different diurnal profiles between early and late chronotypes, including differences in psychomotor vigilance and executive performance.

Experimental and review studies indicate that attention might be more when testing is at the individual's preferred biological time (Taillard et al., 2021; May et al., 2023).

4.2 The processing speed and reaction time

Reaction time is a very sensitive indicator of the efficiency of psychomotor and cognitive processing. Laboratory and field studies have shown that reaction time varies over the course of the day (Dijk et al., 1992; Wright et al., 2002). Facer-Childs and Brandstaetter (2015) showed that peak performance timing varied by circadian phenotype and that the biological timing was more important than clock time. Facer-Childs et al. (2018) also found that there were different diurnal performance profiles between early and late chronotypes, with late chronotypes having poorer performance in the morning on several measures.

The results are especially important for reaction-time based cognitive tests, as the speed at which a person responds to a test may be influenced by the time of day the test is administered, and whether it is an optimal or suboptimal time.

4.3 Memory and learning

Synchrony effects have also been found in the cognitive domain of memory. The time-of-day effects can vary depending on the type of memory being tested. Some types of implicit memory seem to be less susceptible to chronotype-related timing effects than semantic and declarative memory tasks (Wiłkość-Dębczyńska & Liberacka-Dwojak, 2023). Barner et al. (2019) examined the time-of-day effects on prospective memory and found evidence of day-to-day variation in memory performance. Another biological significance of sleep and memory is that good sleep helps consolidate memory and then enhances cognitive functioning. Therefore, the memory differences between chronotypes could be due to differences in circadian timing as well as sleep timing and sleep quality.

5. Chronotype and Executive Functions

Executive functions encompass inhibitory control, cognitive flexibility, planning, reasoning and decision making. These functions are particularly sensitive to changes in alertness and sleep pressure. Previous studies have demonstrated that chronotype and time of day may affect executive aspects of attention (Matchock & Mordkoff, 2009). Evidence of synchrony effects has also been obtained in studies employing inhibitory-control tasks, especially when neural measures are taken. For instance, Rabi et al. (2022) found differences in neural measures of inhibitory control across time of day in younger and older adults.

Decision-making may also vary with circadian timing. Ingram et al. (2016) showed that time of day and chronotype may affect decision-making, and molecular circadian measures showed further evidence of biological timing differences. Leone et al. (2017) also found that the decision-making strategies vary throughout the day, based on a large collection of online chess decisions. But not all studies have found a consistent chronotype effect. For instance, Correa et al. (2017) reported that the economic decision-making tasks elicited similar

responses regardless of chronotype and test session. This variability emphasizes the need to take into account the type of task and experimental conditions.

6. The Synchrony Effect

The circadian synchrony concept is a key element in understanding the link between chronotype and cognition. Synchrony is the match between the biological preference and the time of a cognitive task.

For example:

Morning chronotype → morning testing → relative synchrony

Evening chronotype → evening testing → relative synchrony

If testing is done outside the individual's preferred biological time, performance can be relatively decreased, resulting in a synchrony effect (Schmidt et al., 2007; Taillard et al., 2021). Nowack and Van der Meer (2018) showed the synchrony effect in a semantic analogy task, finding that reaction times and cognitive-resource requirements were lowest at optimal times of day. May et al. (2023) then examined evidence on synchrony across attention, memory, decision-making, academic achievement, and neuropsychological assessment, and found that synchrony effects are more pronounced for complex cognitive tasks.

Importantly, recent evidence indicates that it is not a straightforward "morning types perform better" or "evening types perform better" explanation. The main effect of chronotype was observed in over 80% of the reviewed studies, while the synchrony effect was observed in 45.31% of the studies conducted on young and middle-aged adults (Chauhan et al. 2025). The synchrony effects were especially noted in attention, inhibition and memory.

7. Social Jetlag and Circadian Mismatch

Today's social calendar often clashes with personal biological clock. Sleep and wake times in the context of work, school, and social activities may not align with an individual's endogenous circadian preference. The idea of social jetlag was introduced by Wittmann et al. (2006) to refer to the mismatch between biological and social timing. Roenneberg et al. (2019) then reviewed the link between chronotype, sleep debt and social jetlag and pointed out the need to differentiate between biological timing and socially restricted sleep timing. Conventional work and school schedules may cause more social jetlag for late chronotypes, as they are likely to have to get up earlier than they would like to. This can lead to sleep debt on working days and catch-up sleep on free days (Roenneberg et al., 2003; Wittmann et al., 2006; Jankowski, 2017).

Social jetlag has also been associated with academic performance. Haraszti et al. (2014) found a correlation between social jetlag and academic achievement in university students.

8. Shift Work, Chronotype and Cognitive Performance

Shift work is a more extreme example of circadian and social mismatch as it may involve activity during the biological night.

Taillard et al. (2021) highlighted the potential impact of circadian disruption and sleep timing on alertness, attention, memory, response inhibition, and decision-making. Studies of shift workers also indicate that cognitive functioning is affected by the relationship between internal biological time, local clock time, the amount of sleep, and the amount of time awake. When assessing shift-work performance, it is important to consider both internal and external time, as demonstrated by Vetter & Roenneberg (2012). Likewise, Rosa et al. (2021) reported a correlation between chronotype and psychomotor performance in rotating shift workers, but the interaction between chronotype and individual shifts was not always found.

Longitudinal studies also suggest that shift work and short sleep are related to impaired subsequent cognitive functioning. Using UK Biobank data, Ell et al. (2023) found that shift work was related to poorer performance in reasoning and prospective memory in middle-aged and older adults. These results suggest that chronotype should be taken into account in addition to sleep duration, work schedule, time awake, and circadian phase, and not as a standalone predictor of shift-work performance.

9. Light Exposure and Circadian Cognitive Performance

Light is the most potent synchronizer of the human circadian system. Natural light is important to keep the internal clock in sync with the external day-night cycle, and artificial light can alter the timing of the internal clock, especially if it is provided in the evening or at night. In addition to its effect on sleep and circadian rhythms, Gaggioni et al. (2014) showed evidence that light directly affects brain activity, alertness and cognitive responses. Chellappa et al. (2011) also showed that light has non-visual effects on melatonin, alertness and cognitive performance.

This is especially important in the modern world, where artificial light and electronic screens can disrupt sleep schedules and lead to circadian misalignment, particularly during the evening. A recent review suggests that exposure to light at night may affect melatonin and circadian phase and affect sleep and performance in shift-work settings.

10. Factors Influencing the Relationship Between Chronotype and Cognition

Several factors are involved in the relationship between chronotype and cognitive performance: Like-Age, Sleep duration, Sleep quality, Sleep deprivation, Time awake, Sleep inertia, Time of testing, Task difficulty, Task duration, Work schedule, Light exposure, social jetlag etc. Wiłkość-Dębczyńska and Liberacka-Dwojak (2023)

identified the following factors that can alter the chronotype-cognition relationship: age, task difficulty, task duration, wake duration, testing method, sleep quality, and sleep inertia.

Age is a significant factor. Older adults may exhibit greater relationships between optimal cognitive performance and their preferred biological timing, while younger adults may have later circadian preferences (May et al., 2023; Rabi et al., 2022).

11. Current Evidence and Research Gaps

The literature is growing in support of the notion that cognitive performance should be examined in terms of biological time, not just clock time. But there are some significant gaps.

First, the cognitive performance is not consistently predicted by chronotype. The recent systematic review by Chauhan et al. (2025) shows that most studies did not reveal a significant main effect of chronotype.

Second, synchrony effects vary from one cognitive domain to another. Attention, inhibition, and memory seem to have relatively strong evidence; some evidence for some forms of working memory and decision making is more variable.

Third, numerous studies have been carried out in students or healthy young adults. There has been less focus on occupational groups, shift workers, rural populations and populations exposed to different environmental light conditions.

Fourth, there are relatively few studies that look at all of the following:

Chronotype + time of day + sleep + objective cognitive performance + occupational schedule.

This is an important direction for future research.

12. Future Research Directions

Future research should go beyond the mere comparison between morning and evening chronotypes and investigate the interaction between chronotype, circadian phase, time of day and cognitive demands. Longitudinal studies that integrate questionnaires (MEQ or MCTQ) with actigraphy and objective circadian markers (melatonin or core body temperature) would offer more evidence. Several cognitive domains such as reaction time, sustained attention, inhibitory control, working memory, and decision-making should also be studied.

Shift workers are an important population as their work hours may lead to significant mismatch between the timing of biological functions and the time of activity. The use of chronotype scheduling and personalized evaluation of the timing of performance may thus be considered as a promising field for future studies in occupational research, but further evidence of their efficacy is needed.

13. Conclusion

The timing of sleep, wakefulness, alertness and daily activity is an important individual difference, called chronotype. Circadian and homeostatic processes also interact to cause variation in cognitive performance throughout the 24-hour day. There is evidence that attention, vigilance, reaction time, memory and executive functions can differ as a function of chronotype and time of day.

The most important concept emerging from the literature is circadian synchrony. Cognitive performance may be relatively better when cognitive demands occur during an individual's optimal biological period. On the other hand, social schedules, artificial light exposure, sleep restriction and shift work can cause circadian mismatch, and can have a detrimental effect on cognitive function. But there is no evidence to support the idea that one chronotype is always linked to better cognitive functioning. Rather, the relationship seems to be one that is dependent on the interaction between individual biological timing and the timing of cognitive demands. This interpretation is supported by recent systematic evidence, which indicates that there is little evidence for a main effect of chronotype, but more evidence for synchrony effects in specific cognitive domains.

Therefore, future studies should take into account the interaction between chronotype, time of day, sleep and environmental/occupational timing as a comprehensive approach to individual differences in human cognitive performance.

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