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For Whom (and When) the Time Bell Tolls: Chronotypes and the Synchrony Effect

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Abstract

Circadian rhythms are powerful timekeepers that drive physiological and intellectual functioning throughout the day. These rhythms vary across individuals, with morning chronotypes rising and peaking early in the day and evening chronotypes showing a later rise in arousal, with peaks in the afternoon or evening. Chronotype also varies with age from childhood to adolescence to old age. As a result of these differences, the time of day at which people are best at attending, learning, solving analytical problems, making complex decisions, and even behaving ethically varies. Across studies of attention and memory and a range of allied areas, including academic achievement, judgment and decision-making, and neuropsychological assessment, optimal outcomes are found when performance times align with peaks in circadian arousal, a finding known as the *synchrony effect*. The benefits of performing in synchrony with one's chronotype (and the costs of not doing so) are most robust for individuals with strong morning or evening chronotypes and for tasks that require effortful, analytical processing or the suppression of distracting information. Failure to take the synchrony effect into consideration may be a factor in issues ranging from replication difficulties to school timing to assessing intellectual disabilities and apparent cognitive decline in aging.

Keywords

circadian rhythms, synchrony effect, cognition, aging, time of day, chronotype

Humans, like all species, experience regular periods of alertness and arousal that follow a circadian or 24-hour cycle (Foster & Kreitzman, 2004). These rhythms affect physiological, physical, and intellectual functioning for all people, but the exact timing of these circadian rhythms varies systematically among individuals and across the life span. Some individuals, *morning types* or *larks*, rise early and feel mentally and physically at their best in the morning, whereas others, *evening types* or *owls*, peak later in the day and perform and feel best in the late afternoon and evening. From lab to life, performance is often best when morning types perform early in the day and when evening types perform late in the day, or when behavior is in synchrony with one's chronotype. This is referred to as the *synchrony effect*. Whether you are an air traffic controller vigilantly scanning the radar, a chief financial officer reviewing an earnings report, a circuit court judge rendering a verdict, or a high school student learning chemistry, the synchrony between one's chronotype and the time of day a task is executed can affect outcomes (Pink, 2018). In this article, we highlight the robust evidence of synchrony effects spanning across age groups—from studies of attention and memory to decision-making, ethical behavior, neuropsychological assessment, and measures of academic achievement.

Before turning to synchrony effects themselves, we begin with how chronotype is measured, its apparent near universality, and its developmental trajectory. An individual's chronotype can be measured using self-report questionnaires that assess perceived alertness across the day, preferred times for rising and retiring, and cognitive and physical prowess throughout the day. There are several questionnaires in use with adults (see Di Milia et al., 2013, for a review) and others with

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children (e.g., Ishihara et al., 1990). The measures have good test–retest reliability and, critically, correlate well with physiological and behavioral measures of circadian arousal, including body temperature, hormone secretion, pulse rate, and sleeping and waking behaviors (e.g., Díaz-Morales & Randler, 2017; Randler et al., 2016); they also correlate well with each other (e.g., Goldin et al., 2020; Zavada et al., 2005).

Circadian preferences or chronotypes have been assessed in many parts of the world—from Europe and Asia to North and South America—and across the life span with strikingly similar findings (Díaz-Morales & Parra-Robledo, 2018; Ishihara et al., 1990; Kim et al., 2002; Mecacci et al., 1986; Rahafar, Randler, Díaz-Morales, et al., 2017; Roenneberg et al., 2004; Vagos et al., 2019). Young prepubescent children show morningness tendencies, with early rising times and waning energy later in the day (Carskadon et al., 1993; Díaz-Morales & Parra-Robledo, 2018; Randler & Truc, 2014). With the onset of puberty between the ages of 12 and 14, a shift toward eveningness occurs; this shift was reported in Italy, Taiwan, Germany, Switzerland, Spain, the United States, France, and Japan, suggesting a biological basis for this pattern (e.g., Díaz-Morales & Parra-Robledo, 2018; Gaina et al., 2006; Giannotti et al., 2002; Ishihara et al., 1990; Kim et al., 2002; Park et al., 2001; Randler, 2011; Russo et al., 2007; Takeuchi et al., 2001).[1] The tendency toward eveningness persists until the age of 20 or so, when there is a gradual shift back toward morningness (Díaz-Morales & Parra-Robledo, 2018; Park et al., 2001; Randler, 2011; Roenneberg et al., 2004). Past work has found that roughly 40% of college students continue to show eveningness tendencies, whereas many (~50%) shift to neutral, with a very small minority showing morningness tendencies (Evans et al., 2017; Intons-Peterson et al., 1998; May et al., 1993; May & Hasher, 1998; Yoon, 1997). Replicating this general pattern, archival data from 23,725 Michigan State University students who completed a chronotype questionnaire as part of a participant pool screening showed that 31% were evening types, 62% were neutral, and fewer than 8% were morning types. Even among neutral types there was a skew toward eveningness, with 60% of neutral types being closer to the evening boundary than the morning boundary. The shift toward morningness progresses through middle age (e.g., Roenneberg et al., 2004; Vagos et al., 2019). For individuals aged 60 and older, the majority (65%–70%) show morningness tendencies, and nearly all the rest are neutral types or people without strong morning or evening tendencies, with very few individuals showing strong eveningness peaks (e.g., May & Hasher, 1998; Mecacci et al., 1986; Suh et al., 2017). The developmental shifts in chronotype are important to consider because, as detailed below, understanding chronotype is essential for optimizing performance across the day as well as for understanding the magnitude of differences between, for example, age groups.

Although our focus is on the synchrony effect, we note two related literatures. First, a large literature on chronotype documents psychological and behavioral differences between morning- and evening-type individuals that are independent of the time of day at which testing occurs and go beyond sleeping or waking preferences. Eveningness, for example, tends to be associated with psychological difficulties (e.g., neuroticism, depression, anxiety, insomnia) and is a risk factor for a number of unhealthy behaviors (e.g., smoking, alcohol and substance abuse) and health issues (e.g., Type 2 diabetes, hypertension, bronchial asthma), whereas morningness tends to be associated with greater conscientiousness, agreeableness, persistence, and greater physical activity (e.g., DeYoung et al., 2007; Hogben et al., 2007; Lee et al., 2017; Lipnevich et al., 2017; Merikanto, Lahti, Kronholm, et al., 2013; Merikanto, Lahti, Puolijoki, et al., 2013; Paine et al., 2006; Randler, 2008b; Randler et al., 2017; Schaal et al., 2010; Taillard et al., 2001; Tonetti et al., 2009; Tsaousis, 2010). Second, a substantial and separate literature examines various aspects of performance across the day (e.g., Carrier & Monk, 2000) without taking into account individual or group differences in chronotype.

We have narrowed our focus here to studies that systematically evaluate the interplay between chronotype and testing time. With some exceptions, we limit our review to those studies that measure individual differences in chronotype, randomly assign people of different chronotypes to specific testing times, and measure performance at discrete times of the typical workday (early morning and late afternoon or evening). We do so because, as will be seen, there are important laboratory as well as real-world synchrony effects. We note that synchrony is not simply a nuisance factor to consider in experimental settings, because it impacts performance in various applied settings, including neuropsychological assessment and academic performance (e.g., grades, standardized tests).

We begin with an overview of the evidence from laboratory experiments showing that synchrony matters for basic cognitive processes, including attention, resistance to distraction, and aspects of memory. We present emerging evidence that differences in these cognitive behaviors are associated with differences in brain functioning over the course of the day. We then review extensive evidence from the persuasion and decision literatures that aligns with the findings from studies on attention and memory in showing that synchrony effects are robust when distraction is present or when tasks require effortful, strategic processing, careful or detailed analysis, or the rejection of strong, well-learned (but inaccurate) responses in favor of less-practiced responses. We consider the evidence that synchrony has even greater significance for older adults, who are more likely than younger adults to show a strong chronotype preference for morning and who often show exaggerated deficits in performance when tested at off-peak times. Finally, we consider important limits to the synchrony effect, most notably that synchrony matters less for individuals with neutral chronotypes or for individuals relying on heuristic processes, easily accessible information, or well-learned, automatic responses.

Laboratory Investigations of Synchrony Effects[2]

Attention, working memory, and susceptibility to distraction

Studies examining synchrony effects on aspects of attention demonstrate better performance at synchronous times relative to asynchronous times for three interrelated tasks: vigilance, working memory, and control over distraction. Several studies with young adult participants have shown that motor learning and vigilance or sustained attention (measured with the flanker task and the sustained attention to response task) are better at peak than at off-peak times of day and that attentional performance is associated with changes in cortical activity over the course of the day (e.g., Lara et al., 2014; Martínez-Pérez et al., 2020; Rabi et al., 2022; Salehinejad et al., 2021; but see Bennett et al., 2008). Individuals are also more successful in detecting and rejecting errors at synchronous times of day (e.g., Buela Casal et al., 1990; Horne et al., 1980), and their response times are faster for demanding or complex attentional tasks like the psychomotor vigilance task and cryptoarithmetic (Natale et al., 2003; Schmidt et al., 2012). Vigilance-type tasks are also used in the mind-wandering literature: Participants are stopped at different points during a repetitive or monotonous task and asked what they had just been thinking of (if not the task itself). Here, too, there is evidence of synchrony, with fewer off-task thoughts or distractions at peak than off-peak times of day (Van Opstal et al., 2021). The impact of synchrony on sustained attention may be more profound for those with attentional deficits, including older adults and individuals with attention-deficit/hyperactivity disorder (e.g., Gabay et al., 2022).

There is also evidence that synchrony affects performance on a range of working memory tasks and measures of executive function (Rowe et al., 2009; Schmidt et al., 2015; West et al., 2002; Yoon et al., 1998). For example, both younger and older adults show better performance on the visuospatial Corsi block working memory task when tested at their peak times compared with off-peak times (Rowe et al., 2009), and on a measure of simple word span (Yoon et al., 2000). However, not all working memory tasks are equally demanding, and the magnitude of the synchrony effect may increase as the working memory load imposed by the task increases (see Schmidt et al., 2015). Increased susceptibility to distraction at nonoptimal times is evident in other tasks as well. One study presented distraction in a classic problem-solving test, the Remote Associates Task. In it, participants were given three weakly related cue words (e.g., SHIP, OUTER, CRAWL) and were tasked with finding the word that links all three (i.e., SPACE). When misleading distractors were presented with the cue words (e.g., SHIP–ocean, OUTER–inner, CRAWL–baby), participants tested at asynchronous times were more likely to be misled by the distractors and showed lower solution rates than people tested at synchronous times (May, 1999).

Another approach to attentional control measured the delayed consequences of prior exposure to distracting information by testing for later use of that information. Two studies presented a target and distractor on each trial, and participants were instructed to focus on or respond to the target only and ignore the distractor. Afterward, participants' memory for distractors was tested using implicit measures (i.e., when the participant was unaware of the link between the original and test task), and both studies reported greater priming for distractors at off-peak than at peak times of day, as if the distraction had "leaked" into the focus of attention (Ngo et al., 2018; Rothen & Meier, 2016; for similar findings, see Kim et al., 2007; May & Hasher, 1998; but see also Li et al., 1998, for an exception). In other studies, researchers found that older adult participants using functional magnetic resonance imaging (fMRI) and a similar behavioral task demonstrated differences across the day in regions of heightened activation as well as in connectivity across regions, measures which correlated with the ability to ignore distraction (J. A. E. Anderson et al., 2014, 2017). It is possible that the breadth or scope of attention is greater at off-peak than at peak times of day, potentially resulting in memory representations that include more information than when attention is under sharper control at peak times of day (e.g., Amer et al., 2022; Weeks et al., 2020; Weeks & Hasher, 2018). This in turn would set the stage for memory-retrieval problems, because people need to search through more information while suppressing nonrelevant thoughts to produce a targeted response (Amer et al., 2022; Ngo & Hasher, 2017).

These findings are consistent with *inhibitory theory*, the idea that excessive automatic activation in response to familiar stimuli needs to be suppressed in order for goals be achieved, which has guided much of the cognitive work done on the synchrony effect (see May & Hasher, 1998; Ngo et al., 2018). The basic assumption is that suppression is less engaged at off-peak times of day than at peak times, enabling automatic, stimulus-driven behavior to proceed but impairing tasks that involve management of distraction or inhibition of competitors at retrieval (Ngo & Hasher, 2017). Many of the cognitive findings, albeit not all, are consistent with this view.

Recognition and recall

Humans (May et al., 2005), rats (Morales-Delgado et al., 2018; Winocur & Hasher, 2004), and even aplysia (Lyons et al., 2005) show better memory at their optimal than nonoptimal time of day. In humans, synchrony effects have been reported on many memory-related phenomena, including implicit memory (Delpouve et al., 2014; Intons-Peterson et al., 1998; May et al., 2005; Rowe et al., 2006; Yoon et al., 1998), retrieval-induced forgetting (Pica et al., 2014), prospective memory (Rothen & Meier, 2017; also see Barner et al., 2019), and metamemory (Hourihan & Benjamin, 2014). Our brief overview of this large literature focuses on recognition and recall.

Many studies show clear synchrony effects for recognition memory (e.g., Hornik & Miniero, 2009; Intons-Peterson et al., 1999; Lehmann et al., 2013; May et al., 1993; Maylor & Badham, 2018; Natale & Lorenzetti, 1997; Ryan et al., 2002; Yoon, 1997). Insofar as there are variables that influence recognition accuracy, these likely play a role in the magnitude of synchrony effects. One such factor is the similarity of foils to targets; the greater the similarity, the poorer the recognition. Indeed, synchrony effects are larger when similarity among options is high (Intons-Peterson et al., 1999; Yoon, 1997), and synchrony may be greater for associative recognition than for item recognition (Maylor & Badham, 2018). Finally, consistent with suggestions of the special nature of face processing (Bruce & Young, 2011; Robotham & Starrfelt, 2017), synchrony effects are not seen in face recognition (Yaremenko et al., 2021a, 2021b).

Recall tests reliably show synchrony effects (May et al., 2005, May & Hasher, 2017) in line with the suggestion that, as with recognition tasks with similar foils, they require more controlled processing because of interference from other items (Hasher & Zacks, 1988; Healey et al., 2010, 2014; Ngo & Hasher, 2017) as well as a lack of environmental support often available in recognition tasks (Craik, 1983). For example, in a classic release from proactive interference paradigm, both younger and older adults showed clear synchrony effects on the number of items recalled for the prerelease trials on which successive lists of items were from the same category (Hasher et al., 2002). When the category changed, all participants except older adults tested at an off-peak time of day showed the expected release from proactive interference, as measured by an increase in recall. There is also evidence that controlled, but not automatic, retrieval processes show synchrony effects (see Puttaert et al., 2018; Yang et al., 2007). For example, Sherman and colleagues (2016) found that evening-type younger adults performed better on a cued-recall task in the evening compared with the morning, an effect that was eliminated by drinking caffeinated coffee before the task (see also Ryan et al., 2002), suggesting that caffeine restored participants' arousal. Finally, Lehmann and colleagues (2013) found that both older and younger adults showed synchrony effects on the Rey Auditory Verbal Learning Test for measures of immediate and delayed recall, recognition, and retroactive (though not proactive) interference.

Neuropsychological correlates of attention and memory

Although the importance of time of day in measuring neural functioning and its correlation with cognition has been noted for some time (e.g., Peres et al., 2011; Schmidt et al., 2012; Song et al., 2019), there is relatively little work that takes individual differences in chronotype into account. For the studies that do consider both time of day and chronotype, the fact that there are synchrony effects in neural patterns of activity is unsurprising given behavioral findings. Imaging studies have used both electroencephalography/event-related potential technology and fMRI. Most have tested only young adults, with evidence of synchrony seen in neural activity in parallel with behavioral studies when vigilance, attention regulation, response control, and working memory were assessed (Facer-Childs et al., 2019; Marek et al., 2010; Orban et al., 2020; Salehinejad et al., 2021; Schmidt et al., 2012; Song et al., 2019; Venkat et al., 2020). Synchrony has also been seen when participants are given no particular task (the resting state; Orban et al., 2020, but see Farahani et al., 2021). The few studies that have included older adults along with young adults as participants report synchrony effects for the ability to ignore distraction using fMRI (e.g., J. A. E. Anderson et al., 2014, 2017) and for the ability to control strong motor responses using EEG/ERP (Rabi et al., 2022).

Persuasion and decision-making

Just as attention and memory are compromised at off-peak times, so too are persuasion and decision-making sensitive to synchrony effects, with potentially profound real-world consequences. Consider, for example, attitude change. Arguments based on complex, detailed information are more effective in producing attitude change at peak times, when individuals can engage in more demanding or analytic style processing (Chebat et al., 1997; P. Y. Martin & Marrington, 2005; P. Y. Martin & Martin, 2013; Yoon, 1997; Yoon et al., 2007). By contrast, at off-peak times people are more easily persuaded by soft tactics such as celebrity endorsements, engaging images, flattery, or attractive speakers (Hossain & Saini, 2013; Yoon et al., 2007). In one study, older adults were asked to review an advertisement for a pain reliever. At peak times, they were persuaded by strong, cogent arguments in the advertisement; however, at off-peak times older adults were more influenced by extraneous persuasive details, such as attractive images (Yoon et al., 2007), with very similar results seen elsewhere for young adults (e.g., P. Y. Martin & Marrington, 2005; P. Y. Martin & Martin, 2013). In another study, researchers reported that at nonoptimal relative to optimal times, young adults were less likely to distinguish between highly credible product reviews (e.g., those provided by *Consumer Reports*) and reviews with less credibility (e.g., those provided by the producer). They were also less wary of high-cost product recommendations made by a salesperson and scored lower on a standardized consumer skepticism scale (Hossain & Saini, 2013). Diminished processing at off-peak times may make individuals less aware of persuasion tactics and less skeptical about them and thus more vulnerable to flashy marketing schemes or deception.

Parallels to these findings can be seen in the decision-making literature: People tasked with making decisions or providing judgments at asynchronous times take more risks, rely heavily on heuristic shortcuts, show diminished strategic reasoning, are prone to error, and are more likely to be biased by stereotypic beliefs than they are at synchronous times (e.g., Bodenhausen, 1990; Castillo et al., 2017; Dickinson & McElroy, 2012; Eyink et al., 2017; Ingram et al., 2016; Kruglanski & Pierro, 2008; McElroy & Dickinson, 2010; Oyebode & Nicholls, 2021). For example, when given puzzles that require reflective thinking to determine a correct solution, participants tested at asynchronous times tend to respond with automatic but incorrect answers rather than executing the deliberate, analytical processing necessary to reach accurate responses (Oyebode & Nicholls, 2021). People also make more conjunction-fallacy errors, suggesting that they are more likely to rely on the representativeness heuristic (a mental shortcut that relies on the perceived similarity of events) in making probability judgments at off-peak times (Bodenhausen, 1990). People are also more likely to render a guilty verdict when biasing stereotypic information is present at nonoptimal times; such biases do not impact verdicts at peak times (Bodenhausen, 1990). In addition, at off-peak relative to peak times it takes people more time to solve logical and mathematical reasoning problems (Natale et al., 2003). These findings align with the premise that individuals are less able, or at the very least less likely, to think deliberately, systematically, or carefully at off-peak times, resulting in compromised decision-making.

Synchrony differences seen in laboratory studies of decision-making translate into real differences in consumer behavior. For example, consumers are more willing to wait in a queue at peak times and are more satisfied with customer service, even when that service is identical to that offered at off-peak times (Hornik et al., 2010; Hornik & Miniero, 2009). Individuals performing at synchronous compared with asynchronous times also invest more time and effort in assigned tasks, are more likely to search for important information, remember more about a product or its attributes, and make better financial investment decisions (Cajochen et al., 2004; Guarana et al., 2022; Hornik et al., 2010; Hornik & Miniero, 2009; Yoon, 1997).

Even ethical decisions—including the likelihood of engaging in deceptive behavior and the willingness to admit to such behavior—are affected by the synchrony between chronotype and time of day. When a large prize was at stake, for example, people were more likely to artificially inflate scores (i.e., to cheat) on a game of chance to increase their odds of winning when tested at off-peak than at peak times (Gunia et al., 2014). Furthermore, when individuals were asked about illegal and unethical transgressions—such as illegally downloading music, cheating on an exam, or driving under the influence—they were more likely to confess to such activities at asynchronous relative to synchronous times (Scherr et al., 2014).

Thus, when people operate at their optimal time of day, they are vigilant, discerning, and skeptical. They are more likely to detect scams and are more effective in filtering out distractions so they can successfully solve problems and make strategic, unbiased decisions. At nonoptimal times, people are less careful and discriminating, so they are more vulnerable to soft persuasion tactics, to stereotypes, to producing strong but unedited responses, and to distraction, and they are less likely to make strategic decisions that are free of bias.

Synchrony effects are larger with age

Several findings of synchrony in older adults have already been presented. We include a separate section here because most people over the age of 60 are morning types and because they generally show larger differences in performance across the day than do younger adults (e.g., Borella et al., 2011; Lehmann et al., 2013; May & Hasher, 1998; Rowe et al., 2009; West et al., 2002; Yoon, 1997). With rare exceptions, studies that test morning-type older adults in the morning versus late afternoon report poorer performance in the afternoon on a range of attention/executive function tasks and memory tasks. For example, regulation of distraction is better in the morning than in the afternoon, as seen in both problem-solving (May, 1999) and implicit memory (Rowe et al., 2006) tasks. Synchrony effects have also been reported for two tasks that require the ability to suppress an inappropriate response: Stroop effects are smaller in the morning than the afternoon (Borella et al., 2011; May & Hasher, 1998; Schmidt et al., 2012), and there are fewer errors in the morning than the afternoon on a stop-signal task that requires the ability to withhold a response to an uncommon event (May & Hasher, 1998).

Older adults are not only better able to regulate attention in the morning than in the afternoon but are also more successful at learning new information in the morning (Lehmann et al., 2013; see also Hasher et al., 2002). Recall is also better in the morning than the afternoon (Intons-Peterson et al., 1999; Lehmann et al., 2013; May et al., 2005; Yang et al., 2007). Other studies report that recognition—of both sentences from a story (May et al., 1993) and paired associates from a list (Maylor & Badham, 2018)—is better at peak than at off-peak times of day, effects tied to greater false alarms to foils that are similar to the actually presented information (see also Yoon, 1997). Consistent with these findings is evidence of a synchrony effect for false memory items—that is, reporting items that were implied, but never actually presented, as old (Intons-Peterson et al., 1999). In addition, there is evidence of a shift across the day from more detailed remembering to more schematic remembering (Yoon, 1997).

Because interference is a major source of forgetting in all memory tasks (see, e.g., Hasher & Campbell, 2020), studies have also investigated the role of competition among candidates for response. Evidence indicates that interference is greater at off-peak times than at peak times of day, thereby reducing retrieval (Hasher et al., 2002; Ngo & Hasher, 2017; Yang et al., 2007). There is also evidence that previously relevant information (which should no longer be part of ongoing cognitive effort) remains accessible after a delay, disrupting subsequent performance at off-peak times (Rowe et al., 2009; Weeks et al., 2020).

Neutral chronotype older adults (May & Hasher, 2017) represent approximately 25% of several samples. To our knowledge, there is only one study directly comparing younger and older participants with this chronotype on cognitive tasks at different times of day (May & Hasher, 2017). In that study, older neutral types performed better in the morning than late in the afternoon on the Logical Memory task and on both Stroop and Trails tasks, whereas younger neutral types showed no effect of synchrony across tasks. We note that versions of these tasks are often used in neuropsychological assessments.

Thus, the majority of older adults appear to be particularly vulnerable to synchrony effects, demonstrating better performance on a wide range of laboratory and real-world tasks in the morning than later in the day. Two major concerns follow from this. First, age differences in the cognitive literature can be exaggerated if older adults are not tested in the morning, an effect that will be magnified if both older and young adults are tested in the afternoon.[3] Second, because older adults are among a group of people often given neuropsychological assessments, we would expect to see synchrony effects there.

Synchrony Effects in Applied Settings

Neuropsychological assessment

The fact that cognitive functions like attention, executive function, memory, and problem-solving fluctuate over the day for individuals with strong chronotypes raises important questions about when neuropsychological assessments are conducted. These assessments play a prominent role in the diagnosis of a range of cognitive impairments and disorders, including Alzheimer's disease, intellectual disability, and attention-deficit disorder. They are also used to determine eligibility for clinical trials, therapeutic interventions, and services, and to guide clinicians in the prescription of medications. Given that neuropsychological assessments are designed to measure basic cognitive processes, such as executive function and memory, that are vulnerable to synchrony effects, it seems likely that performance on these assessments may also depend on the synchrony between an individual's chronotype and the time at which testing takes place.

A number of assessment studies included healthy individuals with strong morningness or eveningness tendencies who were randomly assigned to testing times in the early morning or the evening. Young and older adults were tested across these studies. Performance was better at peak relative to off-peak times on neuropsychological measures of task switching (Bennett et al., 2008; Iskandar et al., 2016; May & Hasher, 1998; Ramírez et al., 2012), verbal fluency (e.g., Allen et al., 2008; Iskandar et al., 2016; but see Bennett et al., 2008), verbal learning (Lehmann et al., 2013; Ryan et al., 2002), visual search (Natale et al., 2003), Stroop competition trials (Burke et al., 2015; May & Hasher, 1998; Ramírez et al., 2012; Schmidt et al., 2012), and reflective thinking (Oyebode & Nicholls, 2021).

Several studies have included people diagnosed with Alzheimer's disease, stroke, or other cognitive impairments. Exaggerated synchrony effects were reported for these individuals on neuropsychological measures of attention, executive function, and memory relative to healthy controls (Paradee et al., 2005, 2008; Wilks et al., 2021). These differences in performance over the day can be clinically meaningful, particularly when medical professionals are using assessment scores or test-retest comparisons to make a diagnosis or determine eligibility for support or treatment. Indeed, Goldstein et al. (2007), using the Weschler Intelligence Scale for Children–III, demonstrated that measures of fluid intelligence in morning-type and evening-type adolescents were consistently higher at peak relative to off-peak times, with composite measures that equated to a 6-point difference in IQ estimates.

Academic performance

In addition to neuropsychological assessments, research on synchrony has also examined academic performance. The basic cognitive functions that have proven to be the most vulnerable to synchrony—attention, working memory, retrieval, detailed analysis—are all skills that contribute to academic success, and there now is a substantial literature on schooling and synchrony effects, with adolescents as the main focus of research. Data from a number of locations (e.g., Germany, Argentina, Iran, northern Russia; Borisenkov et al., 2010; Goldin et al., 2020; Preckel et al., 2012; Rahafar, Randler, Díaz-Morales, et al., 2017) are consistent in reporting that evening-type adolescents have lower grades in high school than do morning-type students (for reviews, see Díaz-Morales & Escribano, 2014; Preckel et al., 2012; Scherrer & Preckel, 2021).

Explanations for these findings often focus on sleep loss because environmental demands (e.g., early school start times) conflict with adolescents' eveningness tendencies, increasing the likelihood that adolescents are regularly sleep deprived (e.g., Alfonsi et al., 2020; Kelley et al., 2015; Wheaton et al., 2016). Studies on delayed start times (often in the range of 30–60 min) report increases in sleep time, improvements in mood and attentiveness, and reductions in tardiness and absenteeism, disciplinary problems, and car accidents (Gomes de Araújo et al., 2022; Kelley et al., 2015, 2017; Thacher & Onyper, 2016; Wheaton et al., 2016). Despite these important behavioral improvements and the increase in total sleep time, reports of academic-achievement gains are relatively rare, with several studies reporting small or even no benefits from additional sleep (e.g., Alfonsi et al., 2020; Boergers et al., 2014; Dunster et al., 2018; Hinrichs, 2011; Owens et al., 2010; Ferrante et al., 2022; Thacher & Onyper, 2016; Wheaton et al., 2016). We note that early school start times, even when delayed by an hour, create a mismatch with adolescents' optimal times. For evening-type adolescents, it is possible that delaying the school start time by an hour in the morning will be insufficient to overcome their circadian mismatch (see, e.g., deBruin et al., 2017), despite the increase in sleep. Instead, midday start times might be helpful (Evans et al., 2017).

Data from college students echo this pattern: Evening-type students are disadvantaged academically, and these challenges go beyond total sleep time. For example, in a study by Eliasson et al. (2010), college students with the highest academic performance had significantly earlier bedtimes and wake times than those with the lowest academic performance, even after controlling for total sleep time and weekend sleep habits (see also Beşoluk et al., 2011). The challenges posed by early class start times for evening-type students may be even greater for those with attention-deficit/hyperactivity disorder (Gabay et al., 2022). A recent normative study found that roughly 50% of first- and second-year students fell into evening categories and gave the recommendation that 11:00 a.m. to 12:00 p.m. start times would be helpful to most students (Evans et al., 2017).

With that said, few of these studies directly considered the role of chronotype as a factor. When chronotype is included, there is some evidence that chronotype may be more important in determining school achievement or cognitive functioning than some aspects of sleep (e.g., Borisenkov et al., 2010; Goldin et al., 2020; Hahn et al., 2012; Scherrer & Preckel, 2021; Zerbini et al., 2017). There is some evidence that chronotype predicts measures of academic achievement over and above measures of sleep, IQ, and conscientiousness (Díaz-Morales & Escribano, 2013; Rahafar, Randler, Vollmer, & Kasaeian, 2017; Scherrer & Preckel, 2021).

Additional studies have spoken to the role of chronotype and its interaction with time of day in influencing the academic performance of adolescents. Two laboratory-based studies reported a synchrony effect in adolescents, whose performance was better at times that matched their chronotype and worse at mismatched times. On both measures of IQ and executive function—the go/no-go task, self-ordered pointing, intra/extradimensional shift, and the Iowa gambling task—crossover interactions were reported: At morning testing times, morning types outperformed evening types, and in the afternoon the data reversed—the performance of morning types fell off, and the performance of evening types improved (Goldstein et al., 2007; Hahn et al., 2012).

Several studies have capitalized on naturally occurring differences in the times at which adolescents learn or are tested. In one, researchers used the fact that students entering a public high school in Buenos Aires were randomly assigned to one of three school start times—7:45 a.m., 12:45 p.m., or 5:20 p.m. (Goldin et al., 2020). The finding across a large sample was consistent with synchrony effects, particularly for the oldest group of students (~17.5 years old). The academic advantage the early chronotype students had in the morning over those with later chronotypes was substantially diminished, and even reversed, when school started late in the day. An additional analysis of this sample revealed that the impact of synchrony is greater for math-related subjects than for language subjects (Ferrante et al., 2022).

In another study, over 400 students were randomly assigned to either a morning or afternoon 4-hour interactive chemistry-learning experience with knowledge tested 1 week later (Itzek-Greulich et al., 2016). For students in the morning session, morning types outperformed evening types, with differences between the two groups disappearing in the afternoon as the evening types' performance improved. There was no evidence of a decline in the performance of morning-type students. A third study on adolescents compared grades for over 700 students on tests randomly assigned to early-morning, late-morning, or early-afternoon exam periods (van der Vinne et al., 2015). Early chronotypes had higher marks than later chronotypes in the two morning testing periods, an advantage that disappeared in the afternoon as the performance of late-chronotype students improved and those of early types declined. Chronotype in interaction with time of day clearly plays an important role in educational achievement for adolescents, and there is evidence that the same might be true for university students (Carrell et al., 2011; Eliasson et al., 2010).

Limits to the Synchrony Effect

The findings reviewed thus far demonstrate the robust impact that synchrony has across a broad spectrum of intellectual functions in the lab and everyday life, with implications for education, neuropsychological assessment, marketing, legal and medical decision-making, and contexts that require vigilant attention. With that said, synchrony does not affect performance on all tasks or for all individuals. With respect to tasks, the benefits of synchrony are most robust when distraction is disruptive to cognitive goals or when solutions involve effortful, analytic processing. Synchrony has little influence when individuals can rely on automatic processing, when information is easily accessible, when tasks require highly practiced, dominant responses, or when there is significant environmental support and minimal distraction. For example, performance is stable over the day for tasks such as naming familiar colors and completing the ends of highly predictable sentences and of words missing their final letters. In addition, vocabulary, speed on simple response time tasks, Trail Making Part A, knowledge of basic trivia, identification of pure tone intensity, and auditory-gap detection all tend to be stable across the day (M. J. Anderson et al., 1991; Bennett et al., 2008; Borella et al., 2011; Fabbri et al., 2013; Hasher et al., 2002, 2005; May et al., 2005; May & Hasher, 1998; Paradee et al., 2005; Song & Stough, 2000; Yang et al., 2007; Yoon et al., 2000).

There are even instances in which performance is better at nonoptimal relative to optimal times of day, specifically when a wider scope of attention allows access to distraction that would otherwise be ignored, at least when that distraction offers an advantage for task completion (May, 1999; May et al., 2005; Wieth & Zacks, 2011). Consider, for example, the Remote Associates Task discussed earlier. If the distraction presented alongside cue words is helpful rather than misleading (e.g., SHIP–rocket, OUTER–atmosphere, CRAWL–attic), participants tested at off-peak times benefit from that distraction and are more likely to generate the solution (SPACE) than those tested at peak times (May, 1999). A similar pattern is observed with insight problems, which require solvers to think outside the box and seek alternative interpretations rather than systematically grind out a solution. For insight problems, performance is best at off-peak times (Wieth & Zacks, 2011).

With respect to individual differences in sensitivity to synchrony, there is evidence that for younger university-aged individuals who do not have strong morningness or eveningness tendencies, the time at which testing occurs during the day matters little. Young neutral types showed no difference in performance over the day (morning, midday, evening) when tested on measures of inhibitory processing, executive function, or verbal memory (May & Hasher, 2017). Older neutral types tended to show best performance on these tasks at midday, though for some tasks (e.g., Stroop, verbal memory), performance was strong both in the morning and midday, suggesting that even older neutral types have increased cognitive flexibility over the day relative to their morning-type peers.

This reduced sensitivity to synchrony for neutral-type individuals may account for some of the discrepant findings regarding the influence of synchrony on cognitive performance, as a number of studies demonstrating small or absent synchrony effects have either intentionally included neutral-type individuals in their sample or failed to assess chronotype altogether (e.g., Barbosa & Albuquerque, 2008; Breslin, 2019; Brown et al., 2005; Bugg et al., 2006; Knight & Mather, 2013; B. Martin et al., 2008; Roeser et al., 2015; Root Kustritz et al., 2022; Rothen & Meier, 2017; Tandoc et al., 2021). Given that up to 50% of young adults and 25% of older adults do not show strong morning or evening preferences, it is likely that samples drawn from the general population will include significant proportions of neutral types, thus diluting the synchrony effects experienced by those with strong chronotypes.

Among studies that have failed to report synchrony effects are several that used large blocks of time (e.g., 8:00 a.m.–12:00 p.m. and 1:00 p.m.–5:00 p.m.) as estimates of morning versus afternoon testing times, resulting in morning and evening sessions that may have differed by only an hour or two; others allowed individuals to assign themselves to testing times (Knight & Mather, 2013; B. Martin et al., 2008; Rothen & Meier, 2017). There are also several studies that anchored testing time to participants' sleep–wake schedule in such a way that the morning sessions for evening-type participants were scheduled significantly later than the morning sessions for morning-type participants (e.g., 11:00 a.m. vs. 8:00 a.m., respectively; Ceglarek et al., 2021; Lewandowska et al., 2018). Synchrony effects in these studies tended to be attenuated or even nonexistent. Our focus has been on testing times that align with the start and end of standard work or school days (approximately 8:00 a.m. and 5:00 p.m.) so as to best capture the likely impacts of asynchrony on real-world cognitive performance. This is a salient concern because, until recently, work and activity schedules have been largely controlled by external forces (e.g., employment and school start times), and people were not free (prior to the COVID-19 pandemic) to set their own schedules.

Summary and Conclusions

Circadian rhythms are powerful timekeepers that influence physiological and intellectual functioning over the day, affecting everything from heart rate, body temperature, and hormone secretion to arousal and cognition. These rhythms vary across individuals, with morning chronotypes rising and peaking in arousal and performance early in the day and evening chronotypes showing a later rise in arousal with peaks in the afternoon or evening. As a result of these individual differences, the time at which people are best at attending, learning, solving analytical problems, making complex decisions, and behaving ethically depends on their chronotype, with optimal outcomes found when performance times are synchronized with peaks in circadian arousal. The benefits of synchrony are most robust for individuals with strong morning or evening chronotypes and for tasks that require effortful, analytical processing or the suppression of distracting information.

That synchrony matters more for individuals with strong chronotypes holds important implications for adolescents and older adults, as circadian rhythms follow a predictable developmental trajectory and teenagers and senior citizens are both more likely to demonstrate strong circadian tendencies. Adolescents experience a significant shift toward eveningness with the onset of puberty, creating academic and behavioral challenges for evening-type teens who must adhere to a typical school schedule that starts early in the morning and ends midafternoon. Older adults, by contrast, tend to be morning types and demonstrate greater differences in performance across the day than do younger adults. Older adults also experience age-related impairments on many of the cognitive processes most vulnerable to synchrony effects. Because older adults are particularly sensitive to synchrony effects, an accurate understanding of age-related differences in cognitive function (and even of changes across the adult life span) will be possible only if circadian arousal and testing times are factored into aging studies.

Together, the findings that cognitive processes are under circadian regulation and that circadian rhythms vary across individuals suggest that consideration of chronotype when scheduling could have far-reaching implications. Synchronization could improve accuracy of neuropsychological assessments and psychoeducational evaluations; raise standardized test scores and learning outcomes; optimize legal, financial, and medical decision-making; and allow for accurate comparisons of different age groups in laboratory studies. Synchrony might also play an influential role in optimizing marketing strategies, political campaigns, and public-service efforts. Synchrony might influence, for example, what type of information is used in the morning versus evening to encourage citizens to get vaccinated against a viral threat or to evacuate in the face of a weather threat. Finally, we note the possibility that the failure to consider synchrony effects in cognition could be one source of the replication crisis in psychology. If time of testing differs from one study to the next, or if the proportion of participants with different chronotypes varies from one study to the next, differences could easily emerge on tasks mediated by processes that are subject to circadian regulation—and, as seen here, there are many such tasks.

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Notes

1. Although these developmental patterns are robust across the globe, we note that chronotype can vary with climate and latitude (Randler, 2008a).
2. Unless otherwise noted, study participants were young adults, most often university students.
3. In our experience, young adults do not typically volunteer to participate in studies in the early morning.

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