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REVIEW ARTICLE

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Circadian preference and physical and cognitive performance in adolescence: A scoping review

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ABSTRACT
Adolescence is a crucial period of development which coincides with changes in circadian rhythmicity. This may augment the impact of circadian preference on performance in this group. We aimed to scope the literature available on chronotypes and their effect on physical and mental aspects of performance in adolescents. Studies were identified by systematically searching bibliographical databases and grey literature. The Morningness-Eveningness Questionnaire was the most frequently reported tool for circadian preference assessment. Academic achievement was the most prevailing outcome, with evidence suggesting that morning type adolescents tend to outperform evening types, yet the results vary depending on multiple factors. Performance in tests of intelligence and executive functions was generally better at optimal times of the day (synchrony effect). Physical performance was examined in 8 studies, with very heterogeneous outcomes. Although the associations between circadian preference and performance in adolescents are evident in some areas, there are many factors that may be involved in the relationship and require further investigation. This review highlights the assessment of physical performance in relation to chronotypes, the multidimensional assessment of circadian preference, and the need for longitudinal studies as priorities for further research.
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Introduction

Humans, as well as other species, show daily rhythms in physiology and behavior which allow them to anticipate and adapt to changing environments (Hasting et al. 2019). These cyclical patterns, known as circadian rhythms, have an endogenous origin and a duration of around, but not exactly, 24 hours (Vitaterna et al. 2001). The internal timekeeping mechanism needs to, therefore, synchronize to the precise 24-hour external cycle through exogenous cues (zeitgebers), such as light, social interactions, or exercise (Mistlberger and Skene 2005). The suprachiasmatic nuclei (SCN) in the anterior hypothalamus regulates this circadian rhythmicity and has a major role in the coordination of temporal patterns in organisms (Vitaterna et al. 2001).

As circadian rhythmicity varies greatly from person to person, individuals can be classified according to their circadian typology (also known as chronotype or circadian preference) as morning types (M-types), neither/intermediate types (N-types/I-types), or evening types (E-types), depending on their sleep habits and preferred times for activity (Adan et al. 2012). Differences in chronotypes can be observed in several biological markers (sleep-wake cycle, body temperature, and melatonin and cortisol release) (Adan et al. 2012) and in neurobehavioral variables (attention, memory, executive functions) (Schmidt et al. 2007). The terms chronotype and circadian preference are generally used interchangeably in research (also throughout this article), but there are some differences between the two concepts. Chronotype refers to the biological patterns of circadian rhythmicity, a reflection of the internal time or circadian phase. On the other hand, circadian preference is a manifestation of chronotype, shown as individual variations in the timing for different activities, including preferences in sleep-wake behaviours (Lipnevich et al. 2017; Roenneberg 2015).

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Chronotype is highly determined by genetic factors (Kalmbach et al. 2017), an influence which has been established not only in adults but also in adolescents (Merikanto et al. 2018). Other individual, environmental, and social aspects are involved, and their partial contribution to shaping circadian typology continues to be the focus of many studies. In relation to gender, for example, a recent meta-analysis in men showed a higher tendency towards a later phase preference (i.e., delayed sleep timing), an effect which diminishes with age (Randler and Engelke 2019). Adolescence is also characterized by a marked shift towards eveningness, which slowly reverts to greater morningness as individuals transition to adulthood (Karan et al. 2021; Randler 2011; Randler et al. 2017; Roenneberg et al. 2004).

The timing of circadian rhythmicity in E-types does not align well with social constructs, such as work and school start times, making this group more vulnerable to circadian misalignments. Consequently, late preferences have been associated with health disorders, both mental and physical (Fabbian et al. 2016), as well as emotional and behavioral problems (Li et al. 2018).

Additionally, circadian rhythms have been shown to affect performance in a variety of tasks. Here, we consider performance as a function of effectiveness and efficiency in a particular task, the result of an action or maximum capability (Burz 2013), and we include both mental and physical aspects given the well-studied connections between action and cognition (Schmidt et al. 2017; Serrien et al. 2007). Research in this area focused initially on time-of-day variations, with an increasing number of studies examining chronotype effects as well. In relation to physical and sports performance, it has been suggested that activities involving high demands of strategy and decision-making have peak performances in the morning, while tasks which require a higher physical effort peak later in the day, possibly linked to body temperature fluctuations (Drust et al. 2005). A recent review by Ayala et al. (2021) also highlights the afternoon as the best time for enhanced athletic performance. Regarding chronotypes, research is less conclusive. The most marked differences are observed in rates of perceived exertion (RPE) and mental fatigue, whereas results on psychophysiological responses seem to vary more across studies (Vitale and Weydahl 2017). Daily fluctuations in cognitive tasks were also associated with oscillations in body temperature in early research by Kleitman (Kleitman, 1939, as cited in Kleitman and Jackson 1950). Later studies suggested that such fluctuations did not necessarily parallel body temperature but were task dependent (Folkard et al. 1976), and that a direct link between physiological variables and performance rhythms cannot be assumed (Carrier and Monk 2000). In relation to chronotype, tasks involving higher order cognitive functions may be more affected by a synchrony effect (better performance at times that match the individual's circadian typology) than those requiring automatic or well learned responses (May and Hasher 1998; Schmidt et al. 2007). Numerous studies have focused on academic performance as well. Researchers have suggested both a direct and indirect effect of chronotype on performance (Zerbini and Merrow 2017), but there is great variability depending on the factors examined.

Over the last decades, several reviews have explored the role of circadian rhythms on performance, both in adult and adolescent populations (Ayala et al. 2021; Carrier and Monk 2000; Drust et al. 2005; Fabbian et al. 2016; Preckel et al. 2011; Reilly and Waterhouse 2009; Roden et al. 2017; Scherrer and Preckel 2021; Tonetti et al. 2015; Thun et al. 2015; Ujma and Scherrer 2021; Vitale and Weydahl 2017; Zerbini and Merrow 2017). The focus has been on time-of-day variations in athletic, cognitive, or academic performance. Some reviews have also examined circadian preference, looking at different aspects of performance separately. To our knowledge, a review considering performance holistically has not been conducted yet. Given the distinctive changes of circadian rhythmicity during adolescence and the potential implications for performance at this important period of physical and mental development, an overview of the available literature to understand the evidence base on the topic is necessary. Such evidence could have practical applications in both educational and athletic settings: design of school and training timetables, testing times, additional data for talent identification programs, and design of other chronobiological interventions, to name a few.

The aim of this review is to provide a comprehensive map of the research conducted in relation to chronotypes and performance in adolescents, and to highlight evidence gaps and key research priorities.

Methods

Our review follows the methodological framework for conducting scoping reviews proposed by Arksey and O'Malley (2005), together with the recommendations from Levac et al. (2010), and the Joanna Briggs Institute (Peters et al. 2020). We also used the Preferred Reporting Items for Systematic Reviews and Meta-Analysis extension for scoping reviews (PRISMA-ScR) checklist (Tricco et al. 2018) (Supplementary material). A protocol was designed and registered in Open Science Framework (OSF) (Vidueira et al. 2021) (https://osf.io/uca3z). Any deviations from the protocol were recorded and will be stated in the review when applicable.

Stage 1: identify the research question

Based on preliminary searches and team discussions, the following research question was formulated: What has been studied in relation to chronotype and its connection to physical and cognitive performance in adolescence?

To have a deeper look at the variables involved, some more specific sub questions were also developed:

- How has chronotype been measured in studies related to circadian preference and performance in adolescents?
- Have studies considered maturation stage and not only chronological age when studying the impact of chronotype on performance in adolescents?
- Which variables have been studied in relation to chronotypes and physical performance in adolescents? (Measurements of physical performance and physiological responses to physical activity).
- Which cognitive functions have been studied in relation to chronotypes and cognitive/academic performance in adolescents?

We had included an additional question regarding whether studies had examined other factors linked to the affective dimension, as preliminary searches indicated that emotional aspects could play a major role in both circadian preferences and academic achievement (Randler et al. 2016a). As we became more familiar with the literature, we observed a range of other variables that had been investigated and therefore we decided to note any additional factors studies had examined, and not only affect.

Stage 2: identifying relevant studies

Eligibility criteria

Studies were included if they met the following a priori inclusion criteria:

- Studies including participants with an average age between 10 and 19 years old (regardless of the age range). The selection of this age range was based on the definition of adolescence by the WHO (World Health Organization 2021). If there were subgroups of participants, the study was included if the association between chronotype and performance in the 10-19 age group was presented separately in the report.
- Studies including chronotype assessment through validated questionnaires (e.g., Morningness Eveningness Questionnaire [MEQ; Horne and Ostberg 1976], Munich Chronotype Questionnaire [MCTQ; Roenneberg et al. (2003)] or objective measurements of chronotype (e.g., actigraphy, sleep diary). Although we had initially aimed to include other objective measures such as dim light melatonin onset (DLMO) and core temperature, it became clear that there were two relatively distinct bodies of literature, one focused on circadian preferences and sleep phases, and one focused on biological circadian phase. While related, the two aspects are different. Therefore, we included only studies assessing circadian preference through validated questionnaires (e.g., MEQ) or sleep phase (e.g., MCTQ, mid-sleep on free days [MSF]) as a proxy for chronotype. This approach is consistent with other reviews on the topic (Scherrer and Preckel 2021; Tonetti et al. 2015; Ujma and Scherrer 2021).
- Studies including objective/subjective measurements of physical performance or physiological responses to physical activity.

OR

- Studies including measurements of academic performance (standardized test or grade point average) or cognitive performance (validated tests to measure cognitive functions, e.g., attention, memory, executive functions). We included school grades both if they were obtained through the institutions or if they were self-reported. Other measures of self-reported school achievement or self-reported functioning were excluded.

Sources of information: primary research, reviews, and meta-analysis, including grey literature. Reviews were only included if they were systematic.

Intervention studies, such as those on the effect of light exposure, were included if the effect of the intervention on performance was reported for each specific chronotype.

Exclusion criteria

- Studies carried out on species other than humans.
- Studies including chronotype assessment if the results did not report the relationship between chronotype and performance. Upon discussion, we decided to include studies even if this relationship was not discussed but all participants belonged to the same chronotype category. We

considered that such studies still showed the performance of that specific chronotype in a task in a particular situation or time of the day, although less relevant for practical applications and extrapolation of results.

- Studies including only measures of school attendance, behavior, teachers' subjective ratings of performance or affective domain (e.g., attitudes, motivation, mood).
- Studies including only neurophysiological measures of executive function (e.g., EEG, fMRI).

Search strategy

The search strategy was developed following a three-step strategy as outlined in our protocol. We conducted a preliminary search to identify key terms, followed by a systematic search combining those keywords, and screening of the reference lists of the identified studies. We conducted a systematic search of 6 databases to identify relevant studies. The databases used for the final search were: PsycINFO, MEDLINE, EMBASE, SPORTDiscus, Web of Science, and SCOPUS. In addition, the following journals were also manually searched, as they have been identified as the ones with the most publications on the topic: Chronobiology International, Journal of Sleep Research, Sleep, and Journal of Biological Rhythms (Norbury 2017). To identify other sources of grey literature we consulted PROQUEST database and Google (searches – general). The searches were conducted in July and August 2021. We did not apply any limitations in relation to languages, type of source or geographical location. Searches were limited to literature published after 1960, as it is in that decade when the first studies on circadian rhythms in humans were conducted (Aschoff 1965). A detailed account of the searches for each database is included in Supplementary materials.

Stage 3: study/source of evidence selection

The identified records from the database searches in Stage 2 were uploaded to Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia (https://www.covidence.org). Duplicates were automatically removed. The titles and abstracts of these records were screened against the eligibility criteria by one member of the research team (VV), with a second member (JB) screening a random 10% of the sample. The percentage agreement between authors was 98.7%. The first reviewer (VV) retrieved and screened the full papers for the included records, and a 10% quality check screening was conducted by the second reviewer (JB). The percentage agreement for final inclusion-exclusion was 88.5% and conflicts were resolved by consensus. When papers or information were missing, authors were contacted for further details. Studies were excluded if the information could not be found. The studies which were excluded after full text screening were recorded, together with the main reason for exclusion (Supplementary materials). Figure 1 depicts the study inclusion process.

Stage 4: charting the data

Based on the data table drafted in our protocol, and after reviewers' discussion, a data extraction table was designed on Microsoft Excel. This included general information about the studies (author(s), year of publication, journal, country, language), as well methodological aspects and outcomes of interest for our research questions. As in previous stages, VV extracted data from all the included studies and JB verified 10% of the records, reaching a high level of concordance.

Stage 5: collating, summarizing, and reporting the results

The relevant data from the included studies was summarized in a table (Table 1). In addition, the results are presented as follows:

- A numerical analysis of the main characteristics of the studies: number of records, chronological and geographical characteristics, population, chronotype assessment, and outcomes.
- A narrative summary of the main findings in relation to chronotype and performance.

We discussed physical and cognitive outcomes separately, as the existing literature makes a clear distinction between them. As for the cognitive outcomes, the studies were grouped into academic achievement, executive functions, and intelligence. Although fluid intelligence is considered a higher-level function (a combination of reasoning and problem-solving) (Diamond 2013), we deemed it necessary to report it separately given the number of studies (including a review). When there was a high number of records in a specific area, priority was given to those we considered of more relevance in terms of general patterns or remarkable findings, to provide a general overview of what has been studied.

Results

Numerical analysis

A total of 2395 records were identified from the database searches, of which 64 were included after

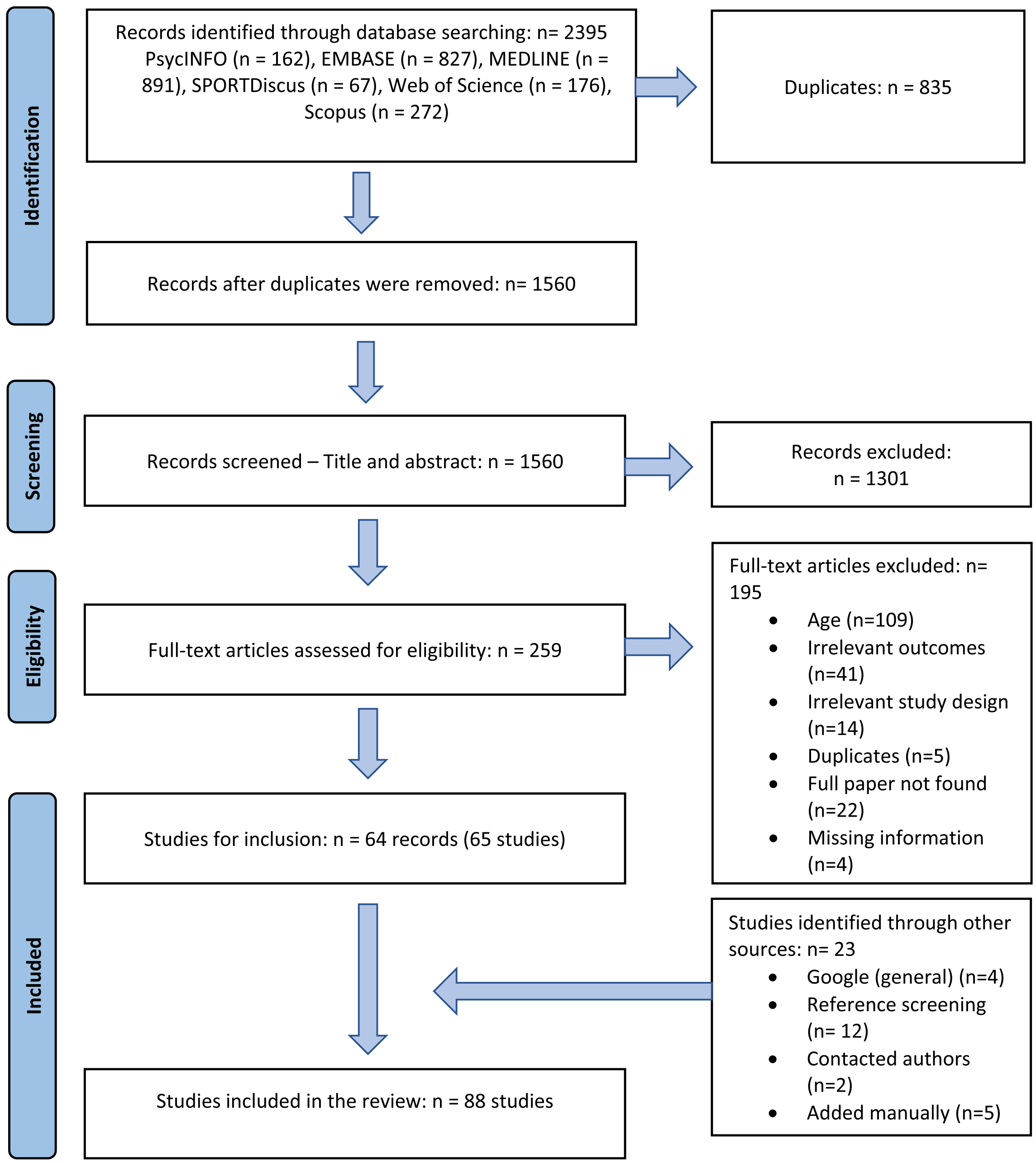

Figure 1. Study/Source of evidence selection flowchart.

removing duplicates and carrying out the screening processes. One of the publications (Scherrer and Preckel 2021) comprises a systematic review and a longitudinal study, thus recorded as two studies. Another 23 studies were identified through other sources. The following results are therefore based on a total of 88 studies (84 primary studies and 4 reviews) (Figure 1), of which 80 are published research and 8 are grey literature (theses, dissertations, and a preprint [Biller et al. 2022; retrieved as a preprint, with the subsequent paper being adopted as the primary reference]). Table 1 shows an overview of these studies.

Similar to the increase in research in relation to chronotype and academic achievement highlighted in the latest review by Scherrer and Preckel (2021), there has been a substantial rise in the number of studies focusing on other aspects of performance in the last decade. Figure 2 shows the chronological distribution of the included studies.

The geographical distribution of the conducted research is presented in Figure 3. The largest contributors were Germany ($n = 13$) and the USA ($n = 10$), followed by Brazil ($n = 9$), Italy ($n = 8$), and Spain ($n = 7$). A lower number of studies were identified in Tunisia ($n = 4$),

Table 1. Summary table of the studies included in the review.

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
Aloui et al. (2013)	Tunisia - English	N=12 (F=0, *M*=12) 18.6 ± 2.4 Highly trained athletes (judo)	MEQ All NT	RPE Handgrip strength: handgrip dynamometer (HG) Maximal Voluntary Contraction (MVC) Muscle power: Wingate test (Peak Power - PP and Mean Power - MP)	For neither types: Lower limb power output and upper limb isometric strength: higher in the afternoon than in the morning during reference night (no sleep deprivation). Decrease in muscle strength and power from before to after a judo combat: higher in the afternoon. Sleep deprivation at the end of the night: decrement of muscle strength and power at 16:00 hours the day after.
Anderson (2017) * Thesis	USA - English	N=39 (F=5, *M*= 34) 14–18 (15.75 ± 1.04) High school athletes	MEQ-SA 15/39 (38%) MT (F=3, *M*=22) 24/39 (62%) ET (F=2, *M*=12)	Computerized neurocognitive testing (CNT) performance: Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT).	No significant differences in CNT performance between MT and ET in verbal memory, visual memory, processing speed, reaction time or total symptoms.
Arbabi et al. (2015)	Germany - English	N=1125 (F=536, *M*=584) 10.22 ± 0.47	CSM MSFsc	Intelligence (fluid): Culture Fair Intelligence Test (CFT 20-R) - German adaptation. Academic achievement: Self-reported grades - Half year grades in Mathematics, German, English and Nature & Culture.	CSM scores: no direct contribution to differences in grades (only mediated by midpoint of sleep and conscientiousness). Positive relationship between morning orientation and higher intelligence. Midpoint sleep: Positive relationship between earlier midpoint sleep and good grades. Later midpoint of sleep: lower scores in intelligence.
Arrona-Palacios and Díaz Morales (2018)	México - English	N=400 (F=205, *M*=195) 13.85 ± 0.70	MESC 101 ET 185 NT 114 MT	Academic performance: self-reported grades (grades of Compulsory Secondary Education: Spanish language, mathematics, English language, and sciences). Inductive reasoning: inductive reasoning subtest (R) from the Primary Mental Abilities battery (PMA-R).	Hierarchical regressions (sex, average sleep length, sleep deficit, inductive reasoning, morningness–eveningness, and SJL): Afternoon shift: chronotype and SJL increased the variance by 0.4%, $F(6,193) = 2.428$, $p < 0.05$. Morning shift: chronotype and SJL increased the variance by 1.9%, $F(6, 193) = 6.565$, $p < 0.001$. Orientation to morningness significantly associated with higher academic performance ($\beta = .15$) Chronotype has an influence on academic performance and intelligence only in morning shifts.
Barin (2011) * Dissertation	Brazil - Portuguese	N=202 (F=102, *M*=100) 10.8	Puberty and Phase Preference 122 MT 80 ET	Academic performance: school grades (Portuguese, Science, Social Studies, Maths).	Better performance for ET students than MT students in all subjects in afternoon shift (Significant differences only in 2009, or when 2008 and 2009 combined, but not in 2008 separately).
Beşoluk (2011)	Turkey - English	N=235 (F=104, *M*=131) 17–19 (17.90 ± 0.63)	MEQ 0.9% Definitely evening 11.9% Moderately evening 68.1% Neither types 19.1% Moderately morning	Academic achievement: university entrance examinations score (four subject areas: Turkish Language, Social Studies, Science and Mathematics).	Significant positive correlation between total scores and MEQ scores ($r = 0.232$; $p = 0.007$) (better performance with increasing morningness). Significant effect of circadian typology on total scores ($F(2,128) = 3.117$, $p = 0.048$): MT higher scores than NT and ET.
Biller (2021) *Preprint (subsequent paper: Biller et al. 2022) *Longitudinal	Germany - English	N=63–157 (F=63%-68%, *M*=37%-32%) 14–19	MSFsc	Academic performance: Grades - Sciences (Biology, Chemistry, Maths, Physics, Natural Sciences), Social Sciences (Geography, History), and Languages (English, German, Spanish, French, Latin).	No relationship between chronotypes and grades. Improvements in chronotype (advanced chronotype) with flexible school system were not associated with changes in grades (p=0.845).
Borisenkov et al. (2010)	Russia - English	N=1101 (F=655, *M*=446) 11–23 (16.1 ± 3.1)	MCTQ	School achievement: mean score for last quarter examinations (self-reported).	Poorer school achievement for late chronotypes (55-min phase delay of the sleep-wake rhythm for low and mean school achievement students compared to high achievement students). Stronger effect of chronotype ($\eta2$=0.022) than sleep length ($\eta2$=0.013) on school achievement.

(*Continued*)

Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
Boschloo et al. (2012)	Netherlands - English	N=605 (F=56%, *M*=44%) 11.75–18.63 (14.81 ± 1.64)	MSFsc	School performance: end of term grades of the school year (Dutch, Math, and English).	No relation MSFsc - school performance (R2 = 0.13; MSFsc: B = 0.00; SE(B) = 0.00; β = −0.06; *p* = ns).
Chtourou et al. (2013)	Tunisia - English	N=20 (F=0, *M*=20) 18.6 ± 1.3 Soccer players competing in first division of the Tunisian soccer league	MEQ All moderately MT	Squat Jump (SJ) and Countermovement Jump (CMJ) Tests	In moderately morning types: No stretching condition: SJ and CMJ heights higher in the evening (17:00h) than the morning (7:00h) ($p < 0.01$). Static stretching condition: no significant effect on diurnal variation (impaired SJ and CMJ heights both in the morning and in the evening). Dynamic stretching condition: improvements in SJ and CMJ heights were greater in the morning than the evening ($p < 0.05$)
Clarisse et al. (2010)	France - English	N=17 (F=0, *M*=17) 16yrs 5 months	MEQ 9 MT 8 ET	Selective visual attention: number crossing-out test. (In group and individual situations)	No differences in average performance between MT and ET. MT performed better than ET at the beginning of the morning. MT: In individual situation: maintained performance throughout the day. In group situation: lower performance at the beginning of the day, improvement from morning until evening. ET: performance improved throughout the day. Lower scores in group situation in the morning, optimal performance in the evening in both group and individual situations.
Cohen-Zion and Shiloh (2018)	Israel - English	N=190 (F=113, *M*=77) 15.0–18.3 (16.3 ± 0.8)	SSHS	The Behavior Rating Inventory of Executive Function – Self-Report (BRIEF-SR). Academic performance: self-reported grades.	Significant association between evening preference and lower grades (rs = 0.30, $p < 0.001$). Association between eveningness and higher BRIEF-SR scores (poorer performance): GEC scale (rp = −.38, $p < 0.001$) and two subscales: the BRI (rp = −.32, $p < 0.001$) and the MI (rp = −.38, $p < 0.001$). Strongest predictors of impaired daily executive capacities: evening chronotype and degree of sleepiness.
de Oliveira et al. (2020)	Brazil - English	N=89 (F=57, *M*=32) 15 ± 0.8	MEQ	Attention: Continuous Performance task (CPT)	No significant associations between chronotype and any of the components of attention.
di Cagno et al. (2013)	Italy - English	N=92 (F=92, *M*=0) 13.3 ± 0.5 (athletes: elite gymnasts) 12.8 ± 1.7 (non-athletes)	MEQ Athletes: 6 Moderately MT 28 NT 8 Moderately ET Non athletes: 11 Moderately MT 30 NT 9 Moderately ET	Motor coordination (kinesthetic discrimination and response orientation abilities): from Hirtz's battery (backwards ball throw test, low jump test, hanging target throw test, orientation shuttle run test). Reactive strength: variations of vertical jump (hopping test - HT, and drop jump test - DJ)	No correlations between chronotypes and motor coordination tests, or chronotypes and reactive strength tests. Untrained athletes: more influenced by the time since awakening and alertness than athletes.
di Cagno et al. (2014)	Italy - English	N=40 (F=40, *M*=0) 13.2 ± 0.5 (athletes: elite gymnasts) 12.9 ± 0.6 (non-athletes)	MEQ Moderately MT 3 37 NT	Static and dynamic balance: One leg balance beam test (OBBT), Star Excursion Balance Test (SEBT), Specific rhythmic gymnastics tests (Static: Splits Balance - SB, Dynamic: Risk and balance test)	No correlations between chronotype and balance tests scores ($p > 0.05$).

(*Continued*)

Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
Díaz Morales and Escribano (2013)	Spain - English	N=887 (F=466, *M*=421) 14.2 ± 1.48	MESC 227 MT 380 NT 280 ET	Inductive reasoning: inductive reasoning subtest (R) from the Primary Mental Abilities battery. School achievement: grade point average (GPA) in common subjects (Spanish language, mathematics, English language and social sciences).	Higher scores in inductive reasoning for ET compared to MT (estimated marginal mean = 15.02 (SE=0.39) vs. 13.87 (SE =0.34)). Higher school achievement for MT compared to ET (estimated marginal mean = 15.02 (SE=0.39) vs. 13.87 (SE =0.34)). Morning preference was significantly associated with higher school achievement (b = 0.10) (Hierarchical analysis with age, gender, sleep length, inductive reasoning and M/E)
Díaz Morales and Escribano (2015)	Spain - English	N=796 (F=425, *M*=371) 12–16 (14.1 ± 1.48)	MESC	Primary mental abilities: Spanish adaptation of Thurstone's Primary Mental Abilities (PMA). PMA subtests: verbal (V), spatial (S), numerical (N), reasoning (R), and verbal fluency (VF). Academic achievement: grade point average in common subjects.	M–E was marginally negatively related to inductive reasoning (correlation coefficient −0.07 $p<0.08$) and positively related to GPA (correlation coefficient 0.09 $p<0.05$)., M-E negatively related to inductive reasoning in girls (−0.10 $p<0.05$), but not in boys (−0.08, ns)
Dimitriou et al. (2015)	England - English	N=47 (F=28, *M*=19) 16–19 (17)	SSHS	Academic performance: grade point average (GPA) for autumn and spring terms. Fluid intelligence: Raven's Standard Progressive Matrices Plus (SPM)	GPA was positively correlated with Morningness/ Eveningness scale (0.23, ns).Raven's SPM correlated positively with Morningness/ Eveningness scale (effect not stated). Raven's SPM correlated positively with Morningness/Eveningness scale (effect not stated).
Duarte et al. (2014)	Portugal - English	N=2094 (F=55.3%, *M*=44.7%) 16–23 (16.82 ± 1.25)	CMQ	School achievement: personal and academic data constructed for the purpose.	Correlation between morningness/eveningness and school achievement (r=−0.219) (Morningness/eveningness: predictor of study methods, reading skills, the motivation for study, and overall achievement, varying inversely)
Eberspach et al. (2016)	Germany - English	N=422 (F=292, *M*=130) 16.57 ± 0.65	LOCI	Academic achievement: self-reported grades in the final record for eighteen school subjects, organised in 4 groups: GPA for languages ('LANG'), natural sciences ('MINT'), social sciences ('SOCIAL'), and fine arts ('ART').	Conscientiousness as a mediator:Morningness: positively related to conscientiousness ($\beta = 0.359$, $p < 0.001$) and academic achievement ($\beta = 0.173$, $p = 0.004$; total effect). Eveningness: negatively related to conscientiousness ($\beta = -.274$, $p < 0.001$) and academic achievement ($\beta = -.254$, $p < 0.001$; total effect). Excluding conscientiousness as a mediator: Significant negative relationship between eveningness and academic achievement (−0.156). No significant total effect of morningness in academic achievement.
Escribano et al. (2012)	Spain - English	N=1133 (F=50.5%, *M*=49.5%) 12–16 (14.07 ± 1.26)	MESCYounger (12–14 years old) 226 MT 280 NT 177 ET Older (15–16 years old): 117 MT 201 NT 132 ET	School performance: Self-reported grades: last year grades in the common subjects for all grades of Compulsory Secondary Education (Spanish language, mathematics, English language and social sciences), and subjective level of achievement.	Youngest group (12–14 years old): MT and NT higher grades than ET ($F(2,675)=7.21$, $p<0.001$, $\eta 2p=0.022$). Significant differences between MT and ET ($p<0.001$), NT and ET ($p<0.05$), and no differences between MT and NT ($p=0.51$). Oldest group (15–16 years old): NT higher grades than ET ($F(2,442)=3.86$, $p<0.05$, $\eta 2p=0.018$). Significant differences between NT and ET ($p<0.05$), but not between MT and NT ($p=1.0$), neither MT and ET ($p=0.19$).
Escribano-Barreno and Díaz Morales (2013)	Spain - Spanish	N=435 (F=50.6%, *M*=49.4%) 12–14 (12.94 ± 0.77)	MESC When only more extreme types: 119 MT 117 ET	School performance: self-reported grades in maths and Spanish language-literature.	Positive association M/E - performance in maths (0.16, $p<0.001$) No differences between chronotypes in Spanish language-literature performance.

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Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
Escribano and Díaz Morales (2014)	Spain - English	N=669 (F=351, *M*=318)) 12–16 (14.26 ± 1.31)	MESC	Sustained attention: Square of Letters Test (SLT). Inductive reasoning: Primary Mental Aptitudes Battery-Inductive Reasoning subtest.	Improvements in attention throughout the school day for both MT and ET. No differences in attention in relation to chronotypes. ET boys: higher attention levels compared to MT boys and ET girls (even when tested in the morning)
Escribano and Díaz Morales (2016)	Spain - English	N=342 (F=53.5%, *M*=46.5%) 12–15 (13.23 ± 0.95)	MESC 93 MT 136 NT 113 ET	School performance: Self-reported grades - last year grades in common subjects for all grades of Compulsory Secondary Education (Spanish language, mathematics, English language, and social sciences). The mean of grades was calculated (GPA).	Morningness: positively related to self-reported grades (r=0.11, p < 0.05).
Estevan et al. (2018)	Uruguay - English	N=224 (F=142, *M*=82) 16.6 ± 1.1	MESC	School performance: GPA.	School shift moderated the relationship between M-E and GPA: Afternoon shift: M-E was correlated with GPA (r = 0.20, p = 0.029). M-E was not a significant predictor of GPA (β=0.01, p=0.960)/Morning shift: The variance of GPA increased by 1.5% when adding M-E (β=0.17, p=0.050).
Fabbian et al. (2016) * Review	Italy - English	12 studies (school and school related issues – 6 in adolescents and cognitive/academic performance)		School and school related issues (attention, mood, academic achievement).	Overall: evening orientation is associated with worse academic performance (the relationship changed over time - weaker in university students)
Ferguson et al. (2018)	USA - English	N=402 (F=265, *M*=137) 17–19	MEQ 12 Definitive evening (3%) 95 Moderate evening (24%) 258 Intermediate (64%) 37 Moderate morning (9%) 0 Definitive morning (0%)	Academic performance: GPA	Small but significant correlation between MEQ and GPA (p=0.017) (Higher grades for early chronotypes) ET: significantly lower grades than MT in early classes (2.91 vs 3.43, (t = −4.07, $p < 10^{-4}$), also lower grades in late classes (3.34 vs 3.63) but not significant (t = −1.82, p = 0.07). (Similar grades for MT and ET as the day progresses)
Finimundi (2012) * Thesis	Brazil - Portuguese	N=424 (F=247, *M*=177) 14–17	M/E Chapter II: 227 MT 197 ET	Chapter II School performance: reported by the school.	Best school performance for MT students studying in the afternoon shift (compared to MT studying in the morning and ET in both shifts) (significant differences only in some subjects). MT in the afternoon shift had a higher number passing grades. No significant differences for ET students in relation to morning or afternoon shift in passing grades. ET in morning shift had the higher number of failing grades (especially in chemistry, maths and physics).

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Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
Finimundi et al. (2013a)	Brazil - Portuguese	N=478 (F=51%, *M*=49%) 11–14 (12.52)	M/E 60% MT 40% ET	School performance: grades.	Higher performances in MT in morning shifts: better in Science, Art, Geography and Maths (p<0.05) compared to MT in afternoon shifts. ET similar performance in morning and afternoon shifts, except for Science and Geography (better performance in the morning p<0.05). Same percentage of failing grades for MT and ET overall. Higher percentage of failing grades in afternoon shifts, especially in MT students. Better performances for MT in morning shifts (p=0,000) and ET in morning shifts (p=0,000) in Science, MT in afternoon shifts (p=0,000) and ET in afternoon shifts (p=0,000) in Physical Education, MT in the morning (p=0,000) in Art, MT in the morning (p=0,011) and ET in the morning (p=0,017) in Geography, and MT in the morning (p=0,001) in Math.
Finimundi et al. (2013b)	Brazil - Portuguese	N=902 (F=54%, *M*=46%) 11–17	M/E	School performance: grades.	Higher performance in the morning for both MT and ET at younger ages. Opposite trend as age increases (higher performance in the afternoon). MT in the morning showed higher performance than ET in the morning (except afternoon shift students at 16 years old in History). Failing grades: MT students in the morning and ET students in both morning and afternoon shifts showed increasing percentage of failing grades with increasing age. Failing grades of MT students in the afternoon didn't increase.
Garcia et al. (2012)	Mexico - English	N=8 (F=7, *M*=1) 17–18 (17.75 ± 0.46)	MEQ All intermediate types	Executive functions: cognitive inhibition and flexibility (Stroop-like task with shifting criteria). Sustained attention (time on task).	In intermediate types: Inhibition: high throughout the day and dropped at night and during the early morning. Correct responses (capacity to make shifts) decreased. Inhibition decreases 1–2 hours after lowest body temperature. Flexibility: declined during the night and early morning, 1-h delay with respect to the rhythm in rectal temperature. Sustained attention (time on task): decreased at night and in the early morning.
Giannotti et al. (2002)	Italy - English	N= 1747 (F=981, *M*=766) ET: 17.1 MT:16.8	SSHS 742 ET (315 males and 427 females) 1005 MT (451 males and 554 females)	School achievement: School Sleep Habits Survey (self-reported grades).	E-types poorer school achievement than M-types. Evening preference increased the risk of poor school achievement (OR 1.6, 95% CI 1.02–2.56).
Goldin et al. (2020)	Argentina - English	N=753 (F=48.40% (younger) and 47.63% (older), *M*= 51.60% (younger) and 52.37% (older)) Younger: 13–14 Older: 17–18	MCTQMEQ MEQ	Academic performance: grades (obtained from school registration's system).	Significant correlation between chronotype and school performance (b = −0.157, 95% CI = −0.255 to −0.059, t = −3.157) (higher grades for MT). Morning: MT higher grades than ET. Afternoon: different patterns depending on age, school timing and subject.

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Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
Goldstein et al. (2007)	Canada - English	N=80 (F=39, *M*=41) 11–14 (12.48 ± 1.07)	CMEP	WISC-III Subtests (Vocabulary, Block Design, and Digit Span): Crystallized intelligence (Vocabulary test). Non-verbal reasoning (Block Design). Short term memory/Fluid intelligence (Digit Span).	Fluid intelligence: Interaction chronotype x testing time was significant (F(1, 76) = 5.16, p = 0.03, n2 = 0.06), performance was better at optimal compared to non-optimal times of day (t(78) = 2.29, p = 0.03, d = 0.52). Crystallized intelligence: interaction chronotype x testing time was not significant (F < 1).
Gomes and Silva Bet (2021)	Brazil - Portuguese	N=41 (F=24, *M*=17) 13–17 (14.6 ± 1.01)	MEQ 4 MT 34 NT 3 ET	School achievement: grades from first semester 2019.	No significant relationship between school performance and chronotype.
Hahn et al. (2012)	Canada - English	N=80 (F=39, *M*=41) 11–14 (12.48 ± 1.07)	CMEP 11 years old: Morning (13) Evening (7) 12 years old: Morning (12) Evening (9) 13 years old: Morning (8) Evening (11) 14 years old: Morning (7) Evening (13)	Executive functions: - Inhibitory control: Go-Nogo task. - Updating/working memory: Self-ordered Pointing task. - Set shifting: Intra- and Extra-Dimensional (ID ⁄ED) Shift task. - Variations in cognitive control: Iowa Gambling Task.	EF composite score: Significant chronotype x time of day interaction, F (1,79) = 12.14, $p < 0.001$, η2 = .138: ET performed better than MT in the afternoon (LSD = .3633, $p < 0.05$), MT performed better than ET in the morning (LSD = .5193, $p < 0.01$). Effects of time of day in evening preference (LSD =.4357, $p < 0.05$): ET tested in the afternoon performed better than ET in the morning. In morning preference (LSD = .4468, $p < 0.05$): MT tested in the morning performed better than MT in the afternoon.
Heath et al. (2014)	Australia - English	N=16 (F=56%, *M*=44%) 14–19 (17.4 ± 1.9)	MCTQ	Cognitive alertness: Go-Nogo task.	No significant main effects or interactions chronotype - cognitive alertness (Go-NoGo task speed and accuracy).
Hines (2003)	USA - English	N=103 (F=64, *M*=39) 14–18 (16)	MEQ 5 Moderately MT 66 NT 26 Moderately ET 6 Definite ET	Critical Thinking: Watson-Glaser Critical Thinking Appraisal. Intelligence: Raven's Standard Progressive Matrices Test. Academic performance: GPA.	Significant negative correlation between Raven scores and MEQ scores (r(102) = −0.31, $p < 0.01$.): Greater intelligence for higher morning preferences (as they collapsed raw scores for MEQ as MT=1, NT=2, ET=3). No significant correlation between MEQ and GPA. Synchrony effect: Significant change in performance in Raven test from preferred time compared to non-preferred time of the day (t(11.78) = 4.303, $p < 0.001$).
Hunt et al. (2011)	USA - English	N=63 (F=40, *M*=23) 18–21 (19 ± 1)	MEQ NT 55% Moderate ET 37% Definite ET 8%	Attention and inhibitory control: TOVA. Processing Speed: Wechsler Adult Intelligence Scale (WAIS–IV)—Processing Speed Index subtests.	Omission errors in TOVA: No significant interactions or main effects of time of day and diurnal preference. Response time variability: main effect of MEQ score (F(1,61) = 8.466, p = 0.005, d= 0.50) (NT better than ET - less variability). Overall response time: main effect of both time of day and diurnal preference(Fs(1,60)> 7.3, ps < .01) (faster times in the afternoon, faster times for NT). Commission errors: no main effect of diurnal preference, but main effect time of day (more commission errors in the afternoon).
Indla et al. (2016)	India - English	N=142 (F=97, *M*=45) 17–19	MEQ Moderate MT 31 NT 102 Moderate ET 9	Academic performance: physiology internal assessments.	No significant differences in academic performance between chronotypes

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Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
Itzek-Greulich et al. (2016)	Germany - English	N=473 (F=47.4%, *M*=47.3%, NS=5.3%) 15.3 ± 0.7	MS Morning course: 44.7% MT 52.2% IT 65.8% ET Afternoon course: 55.3% MT 47.8% IT 34.2% ET	Academic achievement: multiple choice test and cloze test (chemistry).	MSFsc correlated negatively with test scores (multiple-choice test: $r = -0.173$, $p < 0.001$; cloze test: $r = -0.181$, $p < 0.001$). Multivariate analysis: MSFsc was significantly related to achievement (ET lower achievement) (Small effect size: $\eta 2p = 0.022$ and $\eta 2p = 0.012$ for multiple choice and cloze test respectively). Association MSFsc - achievement: significant in the morning course but no significant in the afternoon course. No significant interaction MSFsc and treatment time regarding achievement, but ET performed better in the afternoon.
Jarraya et al. (2014a)	Tunisia- English	N=12 (F=0, *M*=12) 18.75 ± 1.7 Experienced handball goalkeepers	MEQ All NT	Reaction time, selective attention, and constant attention: Simple RT test. Stroop Color–Word test. Barrage test (visual-spatial ability and recognition).	In neither types: Significant main effect of time of day on: Selective attention ($F(4,44) = 47.7$, $p < 0.001$) and constant attention ($F(4,44) = 47.7$, $p < 0.001$): best values in the morning. Reaction time ($F(4,44) = 274.9$, $p < 0.001$): best values in the morning. Both rhythms of cognitive performance are desynchronized from the rhythm of core temperature.
Jarraya et al. (2014b)	Tunisia- English	N=12 (F=0, *M*=12) 18.75 ± 1.7 Experienced handball goalkeepers	MEQ All NT	Reaction time (RT), selective attention (SA) and constant attention (CA): Simple RT test. Stroop Color–Word test. Barrage test.	In neither types: Cognitive performance (i.e., RT, SA, and CA) of the handball goalkeepers were time-of-day dependent following partial sleep deprivation. Cognitive performances (RT, SA, CA) decreased significantly from morning to afternoon in all conditions (Reference night-RN, Partial sleep deprivation at the end of the night - SDE, and Partial sleep deprivation in the beginning of the night -SDB) $p<0.001$. RT: more affected by SDE than SDB (percentages of changes higher during SDE ($t = 2.58$, $p < 0.05$)). SA and CA: more affected by SDB than SDE (percentages of changes higher during SDB (for SA: $t = 3.61$, $p < 0.05$, for CA: ($t = 3.96$, $p < 0.05$)).
Kolomeichuk et al. (2016)	Russia - English	N=1666 (F=857, *M*=808) 10–18	MCTQ	Academic achievement: self-reported grades from last quarter examinations.	ET poorer achievement than NT and MT. Significant negative correlation chronotype - academic grades ($r=-0.191$, $p<0.001$) (lower achievement in ET). Linear regression using social jetlag, chronotype, average sleep duration, age and gender as predictors: $F_{5,1547} = 39.165$, $p < 0.001$; corrected $R^2 = 0.11$, gender was the most important predictor followed by chronotype ($\beta=-0.141$, $T=-3.033$, $p<0.002$) and age.
Kolomeichuk and Teplova (2017)	Russia - Russian	N=609 (F=338, *M*=271) 10–18 (Boys: 15.36 ± 1.33, Girls: 15.74 ± 1.56)	MCTQ	Academic achievement: self-reported grades from last quarter examinations.	No significant correlation between chronotype and academic achievement ($r=-0.096$, $p<0.3$). (Only significant correlations chronotype - risky behaviors and academic motivation). Linear regression: chronotype was not a strong predictor of academic achievement. (The most important predictors were sleep duration and gender)

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Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
Lara et al. (2014)	Spain - English	N=27 (F=25, *M*=2) MT:18–27 ET:18–23 MT: 19 ± 2.4 ET: 19 ± 1.4	rMEQ 13 MT 14 ET	Vigilance: PVT Sustained Attention to Response Task (SART)	PVT task: synchrony effect in reaction time (chronotype x time of day: F (1, 25) = 11.71, $p<0.01$, $\eta p^2= 0.32$) (MT faster in the morning and ET in the evening. Faster responses for ET in the evening, no differences between ET and MT in the morning) Attention task: Reaction times - no main effects or interaction in relation to chronotype. Accuracy - interaction between chronotype, time of day and block (synchrony effect) significant for precision strategy, F (1, 25) =5.18, p=0.03, but not for speed strategy, F < 1. Interaction only significant when performing at non-optimal time of day.
Lariche and Haghayegh (2018)	Iran - Persian	N=106 (F=58, *M*=48) High school students	MEQ Females: 36 MT 22 ET Males: 30 MT 18 ET	Wisconsin Card Sorting Test.	Significant differences between chronotypes in relation to preservation errors and incorrect answers responses ($p<0.05$): worse performances in evening types. Better performances at optimal times compared to non-optimal times.
Lee et al. (2015)	Korea - English	N=101 (F=75, *M*=26) BISS group: 17.56 ± 0.47 No BISS group: 17.66 ± 0.54	KtCS	Academic performance: self-reported grades.	Negative correlation between academic performance and KtCS ($r = -0.26$, $p < 0.01$) (lower performance in ET). M-E not a strong predictor of academic performance (β=-0.06 p=0.66).
Lenzhofer (2012) * Dissertation	Germany - German	N=30 (F=47, *M*=55) Sample was 10 2 17.71 ± 0.897	MCTQ 15 MT 15 ET	Fluid intelligence Advanced Progressive Matrices (APM)	No significant differences in APM performance between MT and ET.
Leocadio Miguel and Menna-Barreto (2016)	Brazil - English	N=22 (F=17, *M*=5) 17–21 (18.2 ± 1.2)	MEQ	Temporal judgement (interval timing task): Directional error – DE (the estimation made divided by the real time interval) and coefficient of variation – CV (ratio of the standard deviation to the mean of each subject). Measured with PalmTM Handheld.	No significant relationships between chronotype score and CV or DE. Significant effect of time of day for CV (F (4,105) = 9.3885, p = 0.0000), but not for DE (p > 0.050).
Li et al. (1998)	USA - English	N=32 young adults (+32 older adults) 17–21 and 18–21 18.4 and 18.8	MEQ Younger adults: all evening type. Old adults: all morning type.	Experiment 1: reading performance (reading time and comprehension accuracy). Experiment 2: same as 1 but included a more difficult recall task.	Experiment 1: No synchrony effect for reading time or comprehension for either younger or older adults (both with and without distraction). Experiment 2: Non-significant main effects or interactions considering time of testing for reading time or accuracy.
Lim et al. (2021)	Korea - English	N=340 (F=79, *M*=261) 17.55 ± 3.81	MEQ-K (Korean version of MEQ) 0 definitely MT 13 moderately MT 169 NT 111 moderately ET 61 definitely ET	Anaerobic power: Wingate anaerobic test (WAnT).	Significant differences among chronotypes ($p<0.001$) in all power variables. Power drop (%), mean power (W), mean power (W/kg), and peak power (W/kg) in moderately MT group were significantly higher than definitely ET group.

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Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
Lunn et al. (2021)	UK - English	N=75 (F=41, *M*=34) 13–14 (13.6 ± 0.39)	MCTQ	Inhibitory control: Antisaccade inhibitory control task. (In social and nonsocial contexts).	No significant main effect of chronotype on overall error probabilities (F=2.25 *p*=0.105). Significant chronotype x context interaction (F=3.68, *p*=0.18): significantly lower likelihood of errors in social compared to nonsocial context for IT and ET, no difference in error probabilities for MT). Pubertal timing: lower PDS score (less physical development, *p* = 0.008) significantly predicted an increase in error probabilities.
Martin et al. (2007)	UK - English	N=16 MEG group: 15.2 ± 1.0 EOG group: 15.4 ± 1.4	MEQ MEG swimmers: NT EOG swimmers: moderate ET	Swimming performance: – 150-m swim at 200-m race pace. – 100-m freestyle time trial from a push-off. (Heart rate, rating of perceived exertion, oral temperature, and capillary-blood lactate. Kinematic data)	For MEG- NT & EOG- moderate ET: 150m swim time: faster during evening trials for both groups (only significant for MEG, *P*= 0.001) Maximal swimming performance (100m): significantly slower during morning trials (MEG: *P* = 0.001; EOG: *P* = 0.003). No significant differences between morning and evening trials in heart rate, blood lactate, and rating of perceived exertion.
Martin et al. (2016)	Canada - English	N=57 (F=58.3%, *M*=41.7%) 12–17 (15.0 ± 0.3)	MESC 16 MT 26 IT 15 ET	Academic achievement: French and mathematics grade point average (GPA).	No differences between chronotypes in academic achievement. School shift no significant moderator either.
May et al. (1993)	USA - English	Study 1:*N*=210 younger adults (+91 older adults)18–22 Study 2: N=20 younger adults (+22 older adults) 18–20 (18.8)	MEQ Younger adults: ET Older adults: MT	Study 1: Morningness-Eveningness rating: MEQ Study 2: Memory: recognition accuracy - verbatim recognition of sentences from a series of paragraphs. Reading time	For younger adults (evening types): No significant differences in reading rate from morning to afternoon (F< 1). Improved performance from morning to afternoon in accuracy in memory tasks (F(1, 19) =7.57, MSc = 232.11).
May and Hasher (1998)	USA - English	Study 1: N=48 younger adults (+48 older adults) 17–21 (18.7) Study 2: N=36 younger adults (+36 older adults) 17–21 (18.6)	MEQ Younger adults: ET Older adults: MT	Study 1: Inhibitory functioning: Garden-path sentence processing task (Sentence completion task developed by Hartman and Hasher). Semantic knowledge: performance on vocabulary test (ERVT). Study 2: Stop-Signal Task. Stroop color-naming task. Trail Making Test.	Study 1: for younger adults (all evening types) Strong synchrony effect in inhibitory efficiency: shift from reliable, below-baseline inhibition of no-longer-relevant items at peak times to significant positive priming for those items at off-peak times. Performance on the vocabulary test (ERVT) remained stable across testing times. Study 2: for younger adults (all evening types) Stop Signal task: Stopping probability - no Delay x Testing time interaction, F(2,68) = 1.47, MSE = 86.7, *p* > 0.23. Stopping time - no differences in testing time F(1, 34) = 2.9, MSE = 9,802.5, *p* =. 10. Category decision on go trials: no main effect of testing time. Stroop task: Word card: significantly faster in the evening F(1, 82) = 7.7, MSE = 41.7. Stroop card: no main effect of testing time. Stroop effect: no significant differences across the day. Trail making test: no time-of-day effect.

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Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
May (1999)	USA - English	N=40 younger adults (and 48 older adults) 18–25 (18.6)	MEQ Younger adults: ET Older adults: MT	Inhibition (RAT) Problem-solving performance in the presence versus absence of distraction: Word problems from the Remote Associates Test (RAT)	Synchrony effect in efficiency of inhibitory processes: ability to suppress irrelevant information diminishes at off-peak relative to peak times. Performance is spared over the day when tasks do not involve the suppression of irrelevant or previously relevant information, particularly when participants can rely on well-learned, semantic knowledge.
Mendes (2019) * Thesis	Brazil - Portuguese	Phase1: *N*=435 (F=230, *M*=205) 12–17 (14.03 ± 0.06) Phase 2: *N*=51 (F=26, *M*=25) 12–14 (13.06 ± 0.10)	MEQ	Attention and Working memory: Digit Span Test (from Wechsler Memory Scale-Revised: WAIS - R). Visuospatial short term memory: Corsi Blok-Tapping Task. Episodic declarative memory: MDE - sub test from Wechsler Memory Scale-Revised (WMSR). Reading comprehension: Cloze Test. School performance in Language: DEL - reading habits reported by the students and performance in the subject reported by the teachers.	Attention and working memory: No correlation Digit Span Test and chronotype. Visuospatial short-term memory: marginal correlation between chronotype and backward version of test ($r = -0.36$, $p = 0.05$) if tested in the afternoon (better performance for ET). Reading comprehension (Cloze test): no significant correlation score - chronotype. MDE scores: positive correlation with chronotype (MT students showed better performance) in both shifts and at both testing times. No significant differences in DEL scores. (No correlation between working memory and chronotype but MT performed better in MDE)
Milić et al. (2014)	Croatia - English	N=821 (F=380, *M*=441) 15–19 (Median:17)	MEQ . Definitely Morning Type 0 Moderately Morning Type 32 (3.9%) Neither Type 537 (65.4%) Moderately Evening Type 243 (29.6%) Definitely Evening Type 9 (1.1%)	Academic achievement: final grades in the last semester.	Weak correlation between school success and chronotype (r=0.189, p<0.001) (MT - higher achievement).
Nunes et al. (2021)	Brazil - English	N=33 (F=13, *M*=20) 13–16 (Boys:14.8 ± 1.60 and Girls:14.4 ± 1.51) Competitive swimmers	MEQ	Swimming performance: 50m and 400m front crawl at 8:00 and 18:00	50 m trial: no significant diurnal variation among MT, NT and ET. 400 m trial: NT best performance time in the evening than morning (p<0.05). No statistical difference in performance in MT and ET.
Owens et al. (2016)	USA - English	N=2017 (F=1095, *M*=922) 12.1–18.9 (15.0)	MESC	Self-regulation: Behavior Rating Inventory of Executive Function, second edition, Screening Self-Report Form.	Chronotype significantly predicted self-regulation ($P \leq 0.001$): greater morningness - higher self-regulation (adjusting for covariates: age, sex, race or ethnicity, highest parental education, receipt of free or reduced-price meals, anxiety or mood disorder, and attention-deficit/hyperactivity disorder). Daytime sleepiness and evening chronotype: stronger predictors of poor self-regulation than short nighttime sleep duration.

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Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
Öztürk (2014)	Turkey - English	N=384 (F=46.5%, *M*=53.6%) 11–12	MESC 97 MT 197 NT 90 ET	Reading comprehension: Reading test.	Significant effect of chronotype on reading comprehension test: (F(2, 345) = 3.226, $p < 0.05$): higher achievement for MT than NT, no differences MT-ET or NT-ET. Significant interaction chronotype and achievement scores [F(2, 345) = 3.473, $p < 0.05$]: Morning (9:00am) - MT performed better than NT and ET. Afternoon (1:15pm) - no significant differences between MT, NT, and ET. No significant differences in performance between morning and afternoon for MT, but higher achievement in the afternoon compared to the morning for NT and ET.
Panev et al. (2017)	Russia - English	N=922 (F=63%, *M*=37%) 14–25 (18.4) - Author contacted for average age	MCTQ	Non-verbal intelligence: Raven's Standard Progressive Matrices test (RPM). Academic achievement: average score of academic performance that students obtained during the previous session/quarter (self-reported).	ET had a higher level of intelligence than NT and ET, but only when SJL < 2 hours (F2,305= 3.12, $P < 0.05$, η2 = 0.02) (Small effect size). When SJL>2 hours: no significant differences in intelligence among chronotypes.
Parker (2009) * Dissertation	USA - English	N=162 (F=56.2%, *M*=43.8%) 14–19	MESC	Academic achievement: seven end-of-unit standardized test (technology class).	Interaction of time of day, gender, and preferred learning time was not statistically significant (F (1,133)= 0.77, *p*=38, *r*=0.08). No significant difference when testing at preferred vs non preferred times (F(1,133)=1.67, *p*=0.20, *r*=0.11). No main effect of time-of-day (F(1,133)=0.29, *p*=0.59, *r*=0.05). MT studying in the morning scored better in afternoon tests (and lower when tested at their preferred times). ET and students in afternoon shifts performed better than MT and morning classes students.
Preckel et al. (2013)	Germany -English	N=272 (F=127, *M*=141, NS=4) 15.6 ± 0.74	LOCI	Cognitive ability: Culture Fair Intelligence Test (CFT-20) (German adaptation of the Culture Fair Intelligence Test). Academic achievement: end of year grades in all school subjects.	Eveningness was a significant (negative) predictor of overall grade point average (GPA), math–science GPA, and language GPA (βs between −0.14 and −0.20), after cognitive ability, conscientiousness, need for cognition, achievement motivation, and gender were held constant. Morningness: not a significant predictor of GPA. No correlation morningness - grades. Correlation eveningness - lower marks in overall GPA ($r = -.18$), math–science GPA ($r = -.22$), and language GPA ($r = -.11$).
Preckel et al. (2020)	Luxemburg/ Germany -English	Study 1: *N*=1022 (F=50%, *M*=50%) 14–19 (14.98 ± 0.94) Study 2: *N*=129 (F=58, *M*=70) 14–17 (15.6 ± 0.74)	LOCI Study 1: Low M-E type: 281 MT: 211 ET: 403 High M-E type: 127 Study 2: 12.62% morning types 39.53% evening types 35.66% low M-E type 13.18% high M-E type	Study 1: Academic achievement: GPA, standardized achievement tests (German reading comprehension, French reading comprehension, and mathematics achievement),	Eveningness negatively correlated with GPA (*r*= −0.248) and with not being promoted (*r*=0.155), morningness positively correlated with GPA (*r*=0.096). Significant main effect of circadian preference on GPA: Circadian preference type significantly explained GPA, F(3, 796)=13.114, $p < 0.001$, η2=0.047. (Medium effect size): ET lowest GPA. Circadian preference type had no significant main effect on school achievement test results, F(3, 862)=2.525, *p*=0.056, η2=0.009.

(*Continued*)

Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
Rahafar et al. (2016)	Iran - English	N=158 (F=91, *M*=67) 17.5 ± 0.51	rMEQ 47 ET 84 IT 27 MT	Academic achievement: GPA.	Chronotype: significant predictor of academic achievement only when it was moderated by conscientiousness and only in girls.
Rahafar et al. (2017)	Iran - English	N=269 (F=149, *M*=120) 17–18 (17.47 ± 2.10)	rMEQ	Fluid and crystallized intelligence: Culture Fair Intelligence Test scale-III (CFIT-III) Academic achievement: Grade point average (GPA) - average score of thirteen marks in different major subjects.	Significant positive relationship between GPA and chronotype (r=0.13) and between GPA and intelligence (r=0.34). The variance of school achievement was explained the most by intelligence followed by gender, and chronotype. Chronotype contributed to the variance of GPA even when adjusted for other predictors [F (5, 262) =9.46, p< 0.001, adjusted R^2=0.137], R^2 change=0.015, p< 0.05)
Ramirez et al. (2012)	Mexico - English	N=8 (F=7, *M*=1) 17–18 (17.75 ± 0.46)	MEQ All intermediate types	Inhibition, flexibility, and verbal articulatory dexterity.: Stroop task with shifting criteria.	In intermediate types: Circadian variations in inhibition and flexibility: Performance time in inhibition - oscillations in phase with the circadian rhythm of body temperature Errors in flexibility - phase delay of 100 min with respect to the rhythm of body temperature Errors in inhibition and performance time in flexibility - no correlation with the rhythm in body temperature. Performance worsened in the second half of all activities during the night.
Randler and Frech (2009)	Germany - English	N=811 (F=399, *M*=412)10–17 (13.3 ± 1.4) 10–17 (13.3 ± 1.4)	PMEQ	Academic achievement: self-reported grades (German language, mathematics, and English language).	Significant negative correlation between grades and PMEQ score (r= −0.182; P<0.001) (Better performance in MT). Partial correlations for each subject: mostly significant (but small effect sizes) except for sports (lowest correlation) and religion, social science, general science, biology and German language (r<0.1). Influence of PMEQ on grades (gender as factor and age as covariate): influence on grading, small effect size (F=14.651; P<0.001; $\eta 2$=0.018).
Randler et al. (2016a)	Germany - English	N=90 (F=43, *M*=47) 13–16 (14.65 ± 0.65)	CSM 18 MT 18 ET 52 NT	Academic achievement: mathematical achievement - standardized test from the VERA comparative study on mathematical achievement.	No synchrony effect found: no differences between group in test times (preferred vs non preferred). No correlation grades - CSM score
Roeser et al. (2013)	Germany - English	N=273 (F=166, *M*=107) 14–16 (15.18 ± 0.76)	MEQ 76 MT (27.8%) 104 NT (38.1%) 93 ET (34.1%)	Academic achievement: grades of main subjects (German, English, and Mathematics) and minor subjects.	No correlation between MEQ and academic performance. Negative effect of eveningness on school performance, mediated by daytime sleepiness and low learning motivation. (Indirect relationship: morningness-eveningness - daytime sleepiness - learning goals and refusal to work - academic performance)

(*Continued*)

Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
Roveda et al. (2020)	Italy - English	N=75 (F=0, *M*=75) 14.9 ± 1.79 Non-professional soccer players	MEQ 25 MT 25 NT 25 ET	Lower limb explosive power: Sargent jump test. Agility: Illinois Agility Run Test (IAT). Aerobic endurance: 6-Minute Run Test (6-MRT).	MT higher scores in the morning tests than evening tests (medium effect size on the SJT (0.51) and small on the IAT (0.49) and 6-MRT (0.48)) ET lower scores in the morning tests than evening tests (small effect size on the SJT (0.45), medium on the IAT (0.71), and large on the 6-MRT (0.97)) NT: No chronotype effect on morning and evening test scores.
Russo et al. (2017)	Italy - English	N=3463 (F=50.4%, *M*=49.6%) 13.8 ± 0.5	SSHS 301 MT 347 ET	Academic achievement: last report card grade points in mathematics, science, and Italian.	Significant relationship between grades and M/E: mathematics r=0.14, science r=0.16, Italian r=0.13 (Small effect sizes). Differences in school achievement between the extreme chronotypes: significantly lower grades in ET compared with MT in mathematics (6.0 ± 1.3 vs 6.80 ± 1.4; $p < 0.001$; η2= 0.07), science (6.15 ± 1.3 vs 6.91 ± 1.4; $p < 0.001$; η2= 0.08), and Italian (6.30 ± 1.2 vs 6.88 ± 1.2; $p < 0.001$; η2= 0.05). (Medium size effect).
Scherrer and Preckel (2021) * Study 1: Review * Study 2: Longitudinal	Germany - English	Systematic review: 33 articles Longitudinal study: N=764 (F=403, *M*=361) 16.80 ± 0.58 (at T1)	LOCI	Academic achievement: reported grades in Math, German language, English language, Biology, Sport, and Religion from the latest midterm records.	Systematic review: Positive relation between morningness and school achievement, and negative between eveningness and school achievement. Relations not affected by students' age, sex, or intelligence, but significantly mediated by students' conscientiousness, motivation, and sleep behavior. No significant relation between circadian preference and school achievement when school started in the afternoon. Longitudinal study: Significant positive correlation M and GPA, and negative correlation E and GPA at T1 (0.12 and −0.09 for M and E respectively) and T2 (0.19 and −0.07 for M and E respectively). (Small effect sizes) Reciprocal relations between CP and academic achievement: M predicted a positive development of academic achievement over a two-year period, but E did not significantly predict change. Earlier academic achievement positively predicted a change in M. Higher achieving students developed lower E over time.
Short et al. (2013)	Australia - English	N=130 (F=40%, *M*=60%) 15.6% ± 0.95	SMEQ	School performance: self-reported grade from School Sleep Habits Survey.	Correlation chronotype - GPA: −0.10 (no significant) Small-to-medium indirect effect of chronotype on academic performance (mediated by sleep quality, alertness, and depressed mood)

(*Continued*)

Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
Spruyt et al. (2019)	France - English	N=522 (full sample) Adolescence group: F=51.3%, *M*=48.7% 13.4 ± 1.2	SM (midpoint of sleep)	Attention: Stabilo test. (Momentary lapses of attention - MLA, Reaction time - RT). MLA indexes: Norm index - Subject's baseline response (fastest response five times in a row without mistakes) Speed of attention: best speed index (best RT) and consistent speed index (best RT on five consecutive correct sets). Stability of attention: precision index (good at 3000ms, very good at 1500ms), regularity index (good regularity index - cut off of 40%, very good regularity index cut off of 20%), error index (mistakes during the task).	For adolescent group: SM (midpoint of sleep) contributed to the shared variances between sleep and attention. Norm index increased with later SM for younger adolescents and earlier SM for older ones. Earlier SM for older adolescents decreased very good precision index in short version of the test (and for everyone in the long version).
Tonetti et al. (2015)	Italy - English	N=36 (F=12, *M*=24) 18.14 ± 0.49	MEQ-CA Actigraphy	Academic achievement: grades obtained by students in their school leaving exams taken at the end of the school year.	Significant positive correlation between SE (sleep efficiency) and exam grades (r=0.42), significant positive correlation between MEQ-CA scores and grades (r=0.35). Multiple regression analysis: SE was significantly and positively related to the final grade (Beta = 0.45; $t28 = 2.17; p < 0.05$), MEQ-CA score was not (Beta = 0.14; $t28 = 0.66; p = 0.51$).
Tonetti et al. (2015) * Review	Italy- English	31 studies (15 within the age range 10–19) Overall: 27309 participants		Academic achievement	Association between morning orientation and better academic performance (0.143 (CI [0,129; 0,156], small effect size). Weaker relationships chronotype-academic performance in university students (higher effect sizes in school pupils: 0.166 (CI:0.127 to 0.206) than university students 0.121 (CI 0.080 to 0.163))
Ujma and Scherrer (2021) * Review	Hungary - English	26 studies (11 within the age range 10–19)		Measures of psychometric intelligence.	Age moderates the relationship CP-intelligence: Age group below 18 years old: positive but non-significant relationship (r = 0.027, p = 0.189). Age group 18–25: negative but non-significant relationship (r = −0.026, p = 0.18). Age group over 25: significant negative relationship (r = −0.093, p = 0.031) (eveningness associated with higher intelligence) (Small effect size).
Valdez et al. (2010)	Mexico - English	N=9 (F=9, *M*=0) 16–19 (17.67 ± 1)	MEQ All intermediate types	Sustained attention: continuous performance task (CPT).	In intermediate types: Performance on the CPT declined throughout the recording session (percent of correct responses decreased and reaction time increased). Circadian variations in performance: 3 h delay in relation to rectal temperature for correct responses and a 1 h delay for reaction time. General stability, short- and long-error runs, and short-hit runs: modulated by a homeostatic factor and a circadian effect. Long-hit runs and time on task stability: modulated by a homeostatic factor but did not show circadian variation.

(*Continued*)

Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
van der Vinne et al. (2015)	Netherlands - English	N=741 (F=377, *M*=364) 11–18 (14.1 ± 1.7)	MCTQ	Academic achievement: School grades from randomly distributed in 16 subjects (art, biology, chemistry, Dutch, economics, English, French, geography, German, Greek, history, Latin, management, math, physics, sociology).	Short sleep on schooldays and being a late chronotype predicted lower grades. (ET lower grades: 544 students, 4492 grades, $F_{4,520.6}$ = 3.864, $p = 0.0042$) Significant time-of-day effect when comparing MT and ET (494 students, 3639 grades, $F_{2,3551}$ = 4.171, $p = 0.0155$). Significantly higher grades for MT during the early (08:15–09:45 h) and late (100:0–12:15 h) morning, but no differences in early afternoon (12:45–15:00 h).
Vollmer et al. (2013)	Germany -English	N=1977 (F=965, *M*=1012) 10–17 (13.38 ± 1.57)	CSM	Academic achievement: self-reported grades in English (or other first foreign language), Mathematics, German, and Science (Biology). Selective attention: attention test using standardized instructions (test by Brickenkamp, 1994, measures selective short-time attention with a letter crossing-out test requiring both speed and accuracy).	Significant correlations between chronotype and grades (0.227), and chronotype and attention (0.085) (small to medium and small effect size respectively): Earlier chronotype had better grades and higher attention (Controlling for sex and age). Chronotype (CSM) was a significant moderator of both gradings ($\eta^2 = 0.045$) and attention ($\eta^2 = 0.004$). Chronotype significant predictor of gradings (β=0.231) (moderate) and attention (β=0.058) (small). Fewer errors for MT in the attention test. Decreasing errors for MT and increasing errors for ET throughout the test.
Warner et al. (2008)	Australia - English	T1: *N*=380 (F=242, *M*=138) T2:*N*=310 (F=195, *M*=115) 15–18 (T1: 16.04 ± 0.63, T2: 16.57 ± 0.66)	SMES	Academic achievement: self-reported grades from SSHS.	At T2 (school term): Indirect links between circadian preference and grades (circadian preference affects mood, daytime functioning, and sleep variables). (ET at disadvantage)

(*Continued*)

Table 1. (Continued).

Author, year	Country - Language	Sample	Measure of circadian preference & Distribution of chronotypes	Performance outcomes	Key findings: Chronotype - Performance
Weidenauer (2019) * Thesis	Germany - English	N=30 (F=23, *M*=7) 12–13 (12.53 ± 0.09)	CSM (adolescent version MESSi (for adolescents) 5 MT 21 NT 4 ET	Behavioural attention and concentration: Concentration and attention test FAIR-2 (Frankfurt attention inventory, second edition).	Speed, accuracy and performance values of the test FAIR-2: significantly higher values at test point 2 (afternoon) (speed: $t(29) = -12.24$, $p < 0.001$, accuracy: $t(29) = -3.58$, $p = 0.001$, performance: $t(29) = -11.28$, $p < 0.001$). Positive correlations between CSM and the speed ($r = .373$, $p = 0.05$) and performance ($r = .366$, $p = 0.05$) at test point 1 (morning) (MT higher speed and performance on the FAIR-2). No significant correlation for accuracy. No significant correlations between the score of the CSM and school achievement (speed, accuracy and performance) at test point 1 (morning) or 2 (afternoon). NT: significant differences in all values between test point 1 and 2. MT and ET: only differences in speed and performance between test point 1 and 2. No significant correlations between components of the MESSi (MA, EV, and DI) with the school relevant achievement.
Zerbini et al. (2017)	Netherlands - English	N=426 (F=219, *M*=207) 11–17 (13.06 ± 0.95)	MCTQ	Academic achievement: School grades from geography, history, Dutch, English, biology, mathematics, chemistry, and physics..	Chronotype was negatively correlated with grades (later chronotypes higher grades). Strength of the prediction for chronotype: $\beta = -0.042$. Chronotype had a stronger impact on grades than sleep duration. Effect of chronotype on grades: significant for geography ($b = -0.071$, $t(405) = -2.559$, $p = 0.0108$),biology ($b = -0.145$, $t(254) = -3.423$, $p = 0.0007$), chemistry ($b = -0.141$, $t(162) = -2.412$, $p = 0.0170$), and mathematics ($b = -0.124$, $t(405) = -2.543$, $p = 0.0114$), and not significant for English ($b = 0.014$, $t(405) = 0.315$, $p = 0.7528$), history ($b = -0.050$, $t(405) = -1.316$, $p = 0.1889$), physics ($b = -0.058$, $t(99) = -0.738$, $p = 0.4621$), and Dutch ($b = -0.034$, $t(405) = -1.414$, $p = 0.1581$). Interaction effect between chronotype and subject area: significant ($F_{1,32932} = 73.567$, $p < 0.0001$) (effect of chronotype significantly stronger for scientific subjects compared to humanistic/ linguistic subjects).

Sample information includes total number of participants, sex distribution (F: Female; M: Male), age range if stated, average age; M: Morningness; E: Eveningness; MT: Morning types; NT: Neither types; ET: Evening types; SJL: Social Jetlag; MEQ: Morningness-Eveningness Questionnaire; rMEQ: Reduced Morningness-Eveningness Questionnaire; PMEQ: Pupil Morningness-Eveningness Questionnaire; MEQ-CA: Morningness-Eveningness Questionnaire for Children and Adolescents; CSM: Composite Scale of Morningness; CMQ: Composite Morningness Questionnaire; SMEQ: Smith Morningness/Eveningness Questionnaire; KtCS: Korean version of the Composite Scale for Morningness/ Eveningness; MCTQ: Munich Chronotype Questionnaire; MSFsc: midsleep on free days corrected for oversleeping; MESC: Morningness-Eveningness Scale for Children; CMEP: Children's Morningness-Eveningness Preferences Scale; SSHS: School Sleep Habits Survey; LOCI: Lark-Owl Chronotype Indicator; MESSi: Morningness-Eveningness-Stability Scale improved.

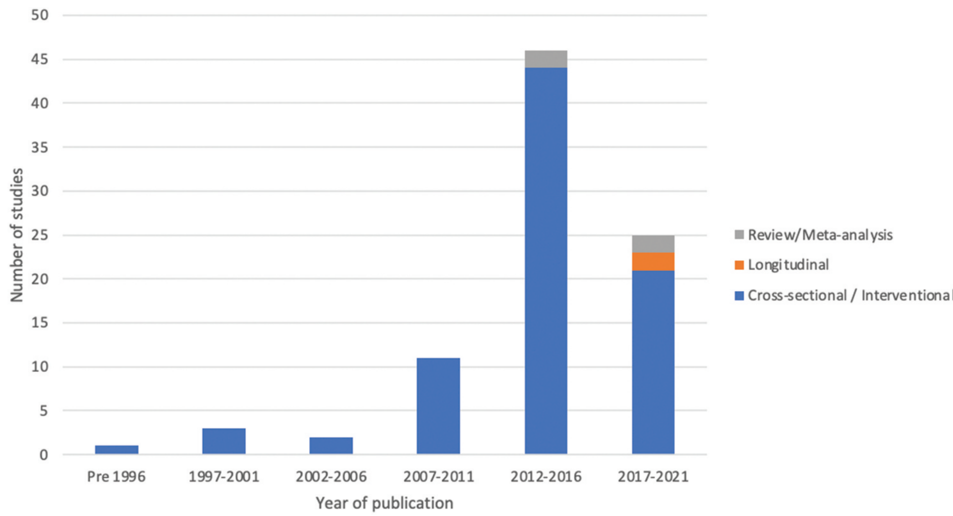
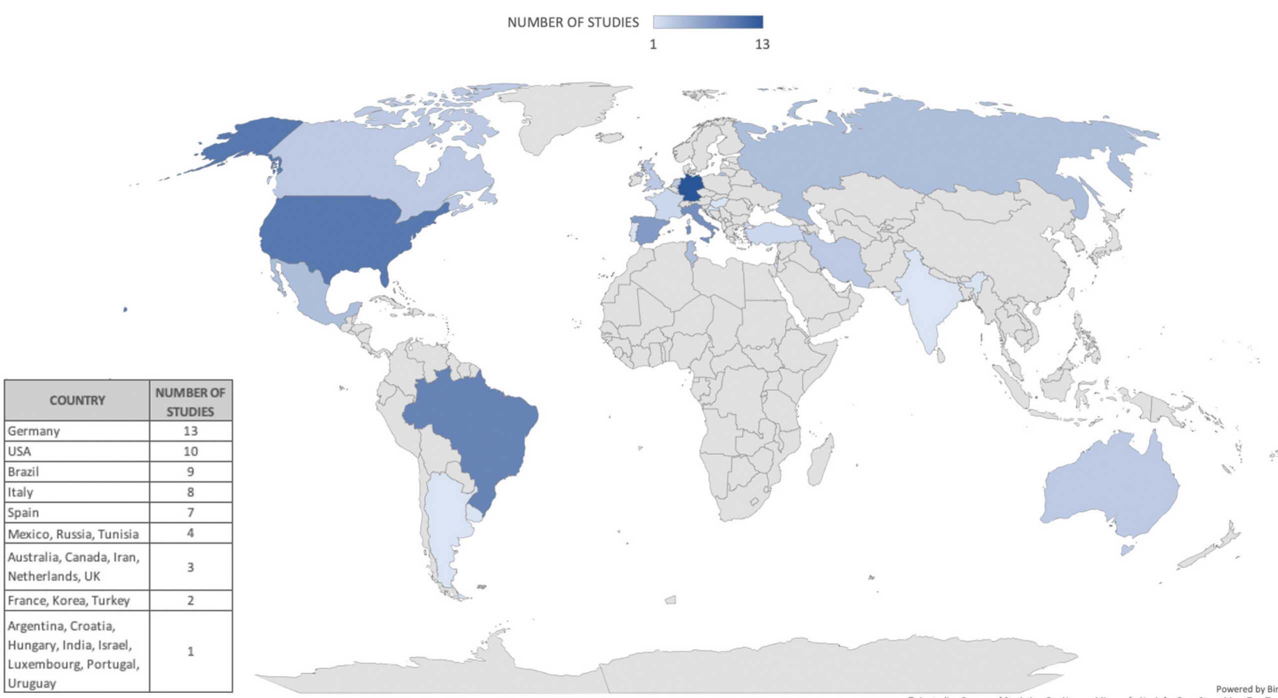


Figure 2. Number of studies by year of publication and type of study.



COUNTRY	NUMBER OF STUDIES
Germany	13
USA	10
Brazil	9
Italy	8
Spain	7
Mexico, Russia, Tunisia	4
Australia, Canada, Iran, Netherlands, UK	3
France, Korea, Turkey	2
Argentina, Croatia, Hungary, India, Israel, Luxembourg, Portugal, Uruguay	1

Figure 3. Geographical distribution of the included studies.

Mexico ($n = 4$), and Russia ($n = 4$), with the remaining studies ($n = 29$; 33%) coming from 16 different countries. Out of the 88 studies, 78 were in English, 6 in Portuguese, and 4 in other languages (Spanish, German, Russian, Persian).

The majority of the studies were cross-sectional, with only 2 longitudinal studies and 4 systematic reviews and meta-analysis (Figure 2). Two of the reviews focused on academic achievement (Scherrer and Preckel 2021; Tonetti et al. 2015), 1 on intelligence (Ujma and Scherrer 2021), and 1 on general health with a section for academic performance (Fabbian et al. 2016).

Sample sizes ranged from 8 to 3463 participants, this number being remarkably lower in studies examining physical/athletic outcomes (largest sample size: 340 participants in Lim et al. 2021).

Chronobiology International was the journal with the largest number of publications included in the review ($n = 18$).

Population

The average age of the participants ranged from 10 to 19 years old. Most of the studies ($n = 68$) had both males and females in their samples, although a few included only males ($n = 7$), only females ($n = 2$), or did not specify sex ($n = 7$). The inclusion of only one sex was more prevalent in studies focusing on the physical/athletic aspects of performance as opposed to academic/cognitive outcomes. The race of the individuals was specified in only a few studies ($n = 6$), but none of them examined racial or ethnic group differences in relation to chronotypes and performance.

In the physical/athletic sample, studies included participants from a variety of sports, mostly high-level athletes: judo (Aloui et al. 2013), soccer (Chtourou et al. 2013; Roveda et al. 2020), gymnastics (di Cagno et al. 2013,2014), swimming (Martin et al. 2007; Nunes et al. 2021), and a mixture of sports (Lim et al. 2021). Several publications investigating cognitive performance outcomes also included athletes in their samples: high school athletes specialized in football, basketball, and track-and-field in Anderson (2017), and handball goalkeepers in Jarraya et al (2014a, 2014b).

Concept: chronotype

An overview of the questionnaires incorporated in the studies can be seen in Table 2. Most of them are unidimensional (morningness-eveningness), and only two of the questionnaires presented in our sample assessed two or three dimensions (Lark-Owl Chronotype Indicator (LOCI; Roberts 1998) and Morningness-Eveningness Stability Scale improved (MESSi; Randler et al. 2016b), respectively). The most used tool was the MEQ ($n = 32$), followed by the Morningness-Eveningness Scale for Children (MESC; Carskadon et al. 1993) ($n = 15$), and the MCTQ ($n = 10$). The LOCI was used in 4 studies and the MESSi in 1 study. Questionnaires assessing circadian preference as a continuum from morningness to eveningness were used considerably more than those which determine chronotype based on sleep phase and those with a multidimensional approach. All studies with physical outcomes used the MEQ. Figure 4 shows the use of questionnaires in the literature in relation to performance outcomes.

Forty-eight studies reported the distribution of chronotypes in the population studied. There was

Table 2. Overview of the questionnaires for chronotype assessment in the studies included in the review.

Questionnaire	Characteristics
MEQ (Horne and Ostberg 1976) Morningness-Eveningness Questionnaire	1 dimension M/E Based on the Swedish language morningness-eveningness questionnaire 19 questions
rMEQ (Adan and Almirall 1991) Reduced Morningness-Eveningness Questionnaire	1 dimension M/E Derived from the MEQ 5 questions, all linked to morning activity
MEQ-CA (Ishihara et al. 1990) Morningness–Eveningness Questionnaire for Children and Adolescents	1 dimension M/E Adapted from the MEQ 19-item with 14 multiple-choice questions and five open questions.
PMEQ (Randler and Frech 2009) Pupil MEQ	1 dimension M/E Adaptation of the German version of the MEQ
CSM/SMEQ/CMQ (Smith et al. 1989) Composite Scale of Morningness Smith Morningness/Eveningness Questionnaire Composite Morningness Questionnaire	1 dimension M/E Developed from psychometric assessment of the MEQ, the Diurnal Type Scale (DTS), and the Circadian Type Questionnaire (CTQ) 13 questions: 9 items from MEQ and 4 from DTS
MESC/CMEP/M/E scale/Puberty and Phase preference (Carskadon et al. 1993) Morningness/Eveningness Scale for Children Children's Morningness-Eveningness Preferences scale Morningness/Eveningness Scale	1 dimension M/E Adaptation of the Composite Scale of Morningness 10 questions
MCTQ (Roenneberg et al. 2003) Munich Chronotype Questionnaire	1 dimension M/E Based on sleep (time in bed, sleep latency and wake time on school/work and free days). It allows to determine chronotype through MSFsc (midpoint of sleep on free days corrected for sleep debt accumulated during school/workdays)
SSHS (Wolfson and Carskadon 1998) School Sleep Habits Survey	1 dimension M/E 63-item questionnaire of sleep/wake habits and daytime functioning. It includes a M/E scale
LOCI (Roberts 1998) Lark-Owl Chronotype Indicator	2 dimensions: M and E 13 items for morningness and 13 items for eveningness
MESSi (Randler et al. 2016b) Morningness-Eveningness-Stability scale (improved)	3 dimensions: M, E, and amplitude Three scales: Morning affect sub-scale (MA), Eveningness sub-scale (EV) and Distinctness/Stability sub-scale (DI)

M= Morningness, E= Eveningness.

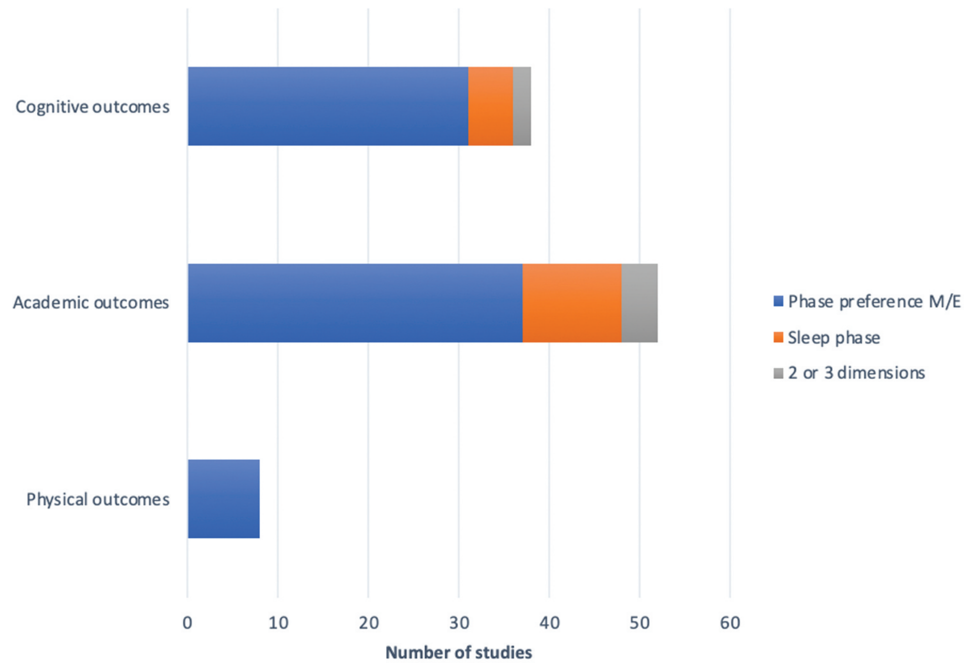


Figure 4. Number of studies by type of outcome and chronotype assessment.

generally a higher number of intermediate types in the samples, although some researchers selected participants based on their chronotype scores and included more representative samples (e.g., Roveda et al. 2020), only M-types and E-types (e.g., Clarisse et al. 2010), or compared groups of young E-types and older M-types (e.g., May 1999).

Concept: performance

Out of the 88 studies included in this review, 80 reported academic/cognitive outcomes and only 8 reported physical/athletic outcomes. Academic achievement, measured in terms of GPA or grades in individual tests or subjects, was the most developed evidence base ($n = 52$). Cognitive functions, including measures of intelligence, were examined in 38 records (one of them a meta-analysis; Ujma and Scherrer 2021). The physical outcomes assessed in the studies ($n = 8$) were heterogeneous, including, for example, anaerobic power (Lim et al. 2021), a mix of simple and complex tasks such as reactive strength and motor coordination (di Cagno et al. 2013), swimming performance (Martin et al. 2007; Nunes et al. 2021), or a combination of tests for power, agility, and endurance (Roveda et al. 2020). While some studies ($n = 11$) reported both academic and other cognitive outcomes, we did not identify any studies including both cognitive and physical outcomes.

Narrative summary: performance outcomes

Cognitive outcomes

Intelligence. In adult populations, research findings into the links between circadian preference and intelligence have revealed positive correlations between late phase preferences and scores in intelligence tests (Ujma and Scherrer 2021). However, several of the studies included in our review reported the opposite trend for younger populations, showing higher intelligence in M-types or individuals with an earlier midpoint sleep (Arbabi et al. 2015; Dimitriou et al. 2015; Hines 2003). A recent meta-analysis by Ujma and Scherrer (2021) concluded that age is, in fact, an important moderator. In their analysis, the relationship between morningness and intelligence changed from a positive to a negative trend with increasing age (childhood to adulthood), but it reached significant levels only in adults over 25 (higher intelligence for E-types). It is possible that the relationship is mediated by other factors. Panev et al. (2017) showed, for example, that E-types outperform M-types in non-verbal intelligence, but only when social jet lag (SJL) is less than 2 hours. Individuals may also perform better when tested at a time of the day that matches their preferred time or peak arousal, an effect known as "the synchrony effect" (a concept introduced by May and Hasher 1998). In line with this theory, performance in tests relying on fluid intelligence (the ability to reason with novel problems, e.g., goal-driven attention regulation and the inhibition of irrelevant information) was better at optimal times of the day compared to off-peak times in a study by Goldstein et al. (2007). They didn't observe the same effect when the tests required crystallized intelligence (the ability dependent on acquired cognitive skills, e.g., semantic knowledge such as facts, concepts, language).

Executive functions. Early work by May et al. (1993) investigated time-of-day differences in a memory task in younger and older adults. They concluded that reading time was not affected by testing time, but recognition accuracy increased from morning to afternoon in E-type adolescents. Later research confirmed this synchrony effect when examining a range of executive functions (Hahn et al. 2012), but such effect seems to disappear when the task requires well-learned or automatic responses (Lara et al. 2014; Li et al. 1998; May 1999; May and Hasher 1998).

The differences in performance during peak versus off-peak times are generally more marked in E-types and when tests are in the morning. Öztürk (2014), for example, did not find significant differences in reading comprehension between morning and afternoon for M-types, but I-types and E-types performed better in the afternoon. The influence of chronotype on academic performance and intelligence was significant only in the morning in a study conducted by Arrona-Palacios and Diaz-Morales (2018) as well.

Several studies reported no associations between chronotype and different measures of attention (de Oliveira et al. 2020; Escribano and Díaz-Morales 2014; Mendes 2019). However, Escribano and Díaz-Morales (2014) observed improvements in sustained attention throughout the school day for both M-types and E-types.

Clarisse et al. (2010) found that the effect of chronotype on selective attention was different depending on the social context. In individual situations, E-types increased their performance from morning to evening, whereas M-types maintained similar levels across the day. In group situations, however, both M-types and E-types improved their performances. Recently, Lunn et al. (2021) found that N-types and E-types showed better inhibitory control in social situations, but the differences between chronotypes were not significant.

Two studies examined the relationship between chronotype and self-regulation. In both cases, eveningness was associated with poorer self-regulation (Cohen-Zion and Shiloh 2018; Owens et al. 2016).

Academic performance. The existing literature on the relationship between circadian preference and academic achievement is more extensive than in other areas of performance, and the findings are more consistent. The evidence in most of the studies indicates that M-types tend to outperform E-types in school subjects (Beşoluk 2011; Borisenkov et al. 2010; Cohen-Zion and Shiloh 2018; Diaz-Morales and Escribano 2013; Escribano and Diaz-Morales 2016; Kolomeichuk et al. 2016; Milić et al. 2014; Randler and Frech 2009; Russo et al. 2017). However, caution must be applied when interpreting these findings as many of the studies reported small effect sizes. In addition, the differences in performance appear to be attenuated or disappear when students attend afternoon courses (Arrona-Palacios and Diaz-Morales 2018; Estevan et al. 2018; Ferguson et al. 2018; Goldin et al. 2020), or when the tests are conducted in the early afternoon instead of in the morning (van der Vinne et al. 2015). The relationship also varies with age. Tonetti et al. (2015), for example, reported a stronger relationship between eveningness and worse academic achievement in school students compared to university students. Finimundi et al. (2013b) observed better academic performance in the morning for all chronotypes during early adolescence and in the afternoon with increasing age.

Several studies, however, did not find significant associations between chronotypes and academic achievement (Boschloo et al. 2012; Gomes and Silva Bet 2021; Indla et al. 2016; Kolomeichuk and Teplova 2017; Martin et al. 2016; Randler et al. 2016a). Contrasting results may be due to testing times, effect of time since awakening or school subject, amongst others. Zerbini et al. (2017), for example, found that the effect of circadian preferences on grades was larger in subjects which require fluid intelligence (scientific subjects) compared to those relying on crystallized intelligence (humanistic/linguistic subjects). Associations between chronotype and grades had also been reported in Maths but not in Spanish language-literature in a study conducted by Escribano-Barreno and Diaz-Morales (2013). The effect of chronotypes on school performance appears to be mediated also by other factors, such as sleepiness, learning motivation, conscientiousness, achievement goals, mood, or alertness (Eberspach et al. 2016; Escribano and Diaz-Morales 2016; Roeser et al. 2013; Scherrer and Preckel 2021; Short et al. 2013; Warner et al. 2008).

Physical performance outcomes

In relation to physical performance outcomes, the small number of studies, together with the heterogeneity in the variables investigated, makes it difficult to compare findings. di Cagno et al. (2013, 2014) studied diurnal variations in reactive strength, motor coordination and balance in elite gymnasts and untrained adolescents. They found differences in performance depending on the time of the day, but no relationships between chronotype and tests scores. Conversely, more recent studies have provided some evidence of the impact of chronotype on performance in this age group. Roveda et al. (2020), reported better performances in the morning for M-types and in the evening for E-types when examining motor skills specific to soccer. They did not find, however, significant differences for N-types. Interestingly, Nunes et al. (2021) observed variations in swimming performance only in N-types, who were faster in the evening during a 400-m trial. Another recent study by Lim et al. (2021) showed better performances for M-types compared to E-types on the Wingate anaerobic test when participants were matched to their preferred time of the day, but they did not study intra-subject variations during the day. A small number of studies investigated time-of-day variations but included only one chronotype category (Aloui et al. 2013; Chtourou et al. 2013; Martin et al. 2007). Their findings generally indicated better performances in the afternoon/evening, with some differences depending on the variables studied.

Sex differences

Sex differences were observed when considering the influence of chronotype on performance. A positive relationship between eveningness and inductive reasoning was evident only in girls in work by Diaz-Morales and Escribano (2015). In their study, girls also showed higher social jet lag (SJL), which was associated with a greater impact on cognitive abilities and GPA. The relationship between chronotype and GPA was found to be mediated by conscientiousness only in females in a study by Rahafar et al. (2016). In contrast, a meta-analysis by Tonetti et al. (2015) reported an association between eveningness and worse academic achievement, but no significant differences. Extreme E-types also achieved lower grades, irrespective of sex, in later work by Russo et al. (2017).

Discussion

This discussion is guided by our research aims, which were to map the research conducted on circadian preference and performance in adolescence, including both physical and cognitive performance, and to ascertain gaps in the evidence base. 71 out of the 88 studies included in the review were published in the last 10 years, which shows an increasing interest in the topic. Our findings reinforce the importance of considering chronotype and time of the day when studying academic performance in adolescents, and highlight the need for research in relation to other cognitive outcomes and physical aspects of performance. The prevalence of unidimensional questionnaires for circadian preference assessment and lack of maturity assessment and longitudinal studies are also discussed.

Chronotype: concept and assessment

In line with the findings reported in other reviews on the topic (e.g., Fabbian et al. 2016; Vitale and Weydahl 2017), the MEQ was the most used questionnaire in the studies included in our review. This well-known tool has been translated to many languages and extensively validated, and therefore constitutes a solid method for circadian preference assessment. However, it is important to note that, although the terms circadian preference and chronotype are commonly seen as synonyms, there are some differences between the two constructs, as outlined earlier. In this sense, the MEQ is a good measure of daily preferences, as opposed to the MCTQ, for example, which measures sleep phase as an indicator of the phase of entrainment (Roenneberg et al. 2019). The choice of the appropriate questionnaire depends, therefore, on which aspect of the construct we want to measure (Roenneberg 2015).

Some practical problems arise when using this type of questionnaire to categorize individuals into circadian types, mostly related to the cut-off points. Around 60% of the population belongs to the intermediate type (Adan et al. 2012). This makes it difficult to find participants representing all categories, especially extreme typologies, and have balanced samples. Authors have used different approaches to solve this issue, which has allowed for more representative samples, but may lead to difficulties when trying to compare findings (Natale and Cicogna 2002). Additionally, studies conducted in different cultures may use different cut-off values (Di Milia et al. 2013). We recommend stating the cut-off points and methods used to select participants if applicable, report the distribution of chronotypes in the sample, and include a good representation of circadian preferences (with extreme types when possible). We also agree with the recommendations by Natale and Cicogna (2002) of using the raw scores or reporting the average score per group, as this will help to see whether participants were close to the established cut-off points and facilitate the interpretation of the results.

Despite the increasing evidence of the multidimensional nature of chronotype, we identified only 5 studies which used questionnaires with two or three dimensions (Eberspach et al. 2016; Preckel et al. 2013, 2020; Scherrer and Preckel 2021; Weidenauer 2019). The findings of these studies are inconsistent, hence more research is needed to understand the associations between different dimensions of chronotype and performance in adolescents.

Population

Maturity status

While inter-individual differences in maturity timing can be pronounced during the adolescent years, few studies incorporated maturity assessment in their methodologies. An exception is the study by Lunn et al. (2021), which included pubertal timing as a covariate. Pubertal maturation has been shown to influence phase preference, with later tendencies observed in more mature individuals during adolescence (Carskadon et al. 1993). The relationship was confirmed when examining melatonin offset times and maturation (Carskadon et al. 1997). In addition, higher levels of testosterone have been associated with higher eveningness (Randler et al. 2012). There is also evidence of sex hormone receptors in the human SCN, which suggests a direct influence of these hormones on circadian mechanisms (Kruijver and Swaab 2002).

Variations in performance are observed in relation to maturity status, both in physical (Albaladejo-Saura et al. 2021; Beunen and Malina 2008) and cognitive outcomes (Cromer et al. 2015; Kovács et al. 2022; Luna et al. 2004).

The different timing of growth spurts and subsequent changes in physical abilities during adolescence, together with the ongoing nonlinear development of cognitive functions, raises the question of whether the effect of chronotype on performance may differ depending on maturation. Therefore, investigating the relationships between chronotype and performance while considering maturity status, and not only chronological age, emerges as a key research priority in the light of the results of this review.

Racial/Ethnic background

We found that most of the included studies did not report the race of the participants. Research has shown racial differences in M/E tendencies (Malone et al. 2016), the length of the free-running period (Eastman et al. 2012), and sleep timing and duration (Combs et al. 2021). Ethnic differences have also been reported in young populations (Kim et al. 2002). Consequently, literature on the associations between chronotype and performance should aim to include diverse populations and account for potential differences derived from racial/ethnic backgrounds.

Age and sex

We observed an underrepresentation of participants towards the lower limit of the studied age range (10–19 years old). While research has generally agreed on a transition from morningness to eveningness starting at around 12 (Adan et al. 2012) and until around 19–20 years old (Karan et al. 2021; Roenneberg et al. 2004), Randler et al. (2017) found a turn to eveningness already at 9 years of age and a peak at approximately 16. Although differences in chronotype assessment, sample size, and cultural background may account for these discrepancies (Randler et al. 2017), the findings suggest that it is possible to observe late phase preferences at early stages of adolescence. It is therefore worth considering the inclusion of young participants and assessing differences between age groups to understand the extent of the impact of circadian preferences on performance across the whole adolescent period.

Women are generally more oriented towards morningness than men (Randler and Engelke 2019). However, possibly linked to pubertal maturation at younger ages, the adolescent shift to higher eveningness and back to morningness happens earlier in girls than in boys (Randler 2011). Some of the studies included in this review found girls to have higher morningness (Duarte et al. 2014), or failed to find significant sex differences in chronotype (Arrona-Palacios and Diaz-Morales 2018; Cohen-Zion and Shiloh 2018; Diaz-Morales and Escribano 2015; Escribano and Diaz-Morales 2016; Giannotti et al. 2002). The disparities in results could be due to variations in chronotype assessment, sample sizes, or age-sex interactions. The associations between circadian preference and performance in relation to sex vary greatly among the included literature as well, with differences observed in some studies (Diaz-Morales and Escribano 2015) but not in others (Escribano and Diaz-Morales 2016). Further studies investigating sex differences in this topic are therefore needed to clarify how all these factors come together to explain performance outcomes.

Performance outcomes

The numerical analysis presented previously highlights some evident gaps in the type of performance outcomes that have been studied. While academic achievement continues to be the main focus of research, executive functions (EF) have been paid less attention, and measurements of physical performance are still sporadic. In future investigations, it might be possible not only to investigate these understudied areas, but also to understand how they interact in relation to circadian rhythmicity.

There is increasing evidence of the links between physical activity and cognitive functioning, and the relationship seems to be reciprocal. Improved cognitive functioning is related to enhanced athletic performances in a variety of sports (Hernández-Mendo et al. 2019; Scharfen and Memmert 2019; Trecroci et al. 2021). Athletes have been shown to score higher in several executive function measures such as inhibition and problem solving (Jacobson and Matthaeus 2014). Additionally, studies have reported positive effects of physical activity on executive functions and academic achievement (Barbosa et al. 2020; de Greeff et al. 2018), and there is evidence that executive functions mediate the relationship between motor ability and academic outcomes (Schmidt et al. 2017).

Despite these findings, chronobiology studies have focused on aspects of performance separately, and the practical applications to different areas are rarely discussed. Therefore, the investigation of multiple areas of performance in relation to chronotype and study of their interactions emerges as a line of research that is worth exploring. A better understanding of which cognitive processes are more susceptible to the synchrony effect would benefit not only academic tasks, but also performance in sport-specific skills and other motor behaviors in which such processes are involved. This could have significant practical implications when planning learning activities, as well as scheduling testing, training, and competition times. Consideration of the individual's chronotype may also be important when examining the effect of physical activity on cognitive and academic outcomes, thus the need of further insight into these individual differences to maximize performance.

Many studies have investigated the direct association between chronotype and performance in a variety of tasks, but there is increasing evidence that the relationship is much more complex. Several studies provided evidence of indirect effects of chronotype on performance (Roeser et al. 2013; Scherrer and Preckel 2021). Possible mediators include conscientiousness, motivation, sleep behavior, alertness, mood, or learning motivation. In the studies reviewed, special attention was given to sleep behaviors, but it does not seem clear whether it is sleep duration, quality, or timing that have the highest impact on cognition and academic achievement. Future work is required to establish the contribution of all these factors to the circadian preference-performance relationship.

When looking at the time of testing, studies have usually incorporated only a morning and an afternoon or evening trial. It could also be argued that, in most cases, the window chosen for the afternoon/evening trials could be too early to show peak performance in more extreme E-types, especially in male populations. Studies in adult athletes have found marked differences in performance in relation to chronotypes when including several testing times during the day and late sessions (Facer-Childs and Brandstaetter 2015). More testing times and late trials may be therefore needed to observe more significant effects in adolescents as well.

Despite the contributions of the existing studies, a clear understanding of the effect of chronotypes on physical performance in adolescents is still lacking. Studies in this area are scarce, and the performance outcomes, characteristics of the participants, and study designs are heterogeneous. Some studies did not have E-types (di Cagno et al. 2014; female sample in Nunes et al. 2021), and most of them lacked extreme type representation. In addition, the sample sizes were generally small, and most studies included only one sex. The majority of the studies were conducted with elite athletes and, whilst it is important to continue advancing knowledge in relation to this group, research in a wider population is needed, as the relationship between chronotype and performance will likely differ in untrained adolescents. Different trends in the time-of-day effect in athletes versus non athletes were found, for example, in the studies by di Cagno et al (2013, 2014). In their research, untrained athletes were also more affected by time since awakening, an aspect which needs to be considered as sizeable differences have been observed between chronotypes in relation to time since awakening in adults (Facer-Childs and Brandstaetter 2015). Lastly, habitual training time could account for differences in the relationship between circadian preference and physical performance, leading to better performances at the athlete's regular training time (Chtourou et al. 2012; Rae et al. 2015). These findings need to be confirmed in adolescents, as the impact of this variable may be different in this age group. Further work is therefore needed to develop a clear picture of the effect of circadian preferences on athletic performance.

Context

Geographical considerations

Several geographical factors have been shown to have an effect on circadian preference. Latitude is considered one of the most important aspects, as it is linked to both temperature and the light/dark cycle (Leocadio-Miguel et al. 2017). A number of studies have revealed an association between higher latitudes and eveningness (Borisenkov et al. 2012; Leocadio-Miguel et al. 2017; Randler 2008; Randler and Rahafar 2017). Randler (2008) also found an age-climate interaction, with different responses depending on the climate zone, as well as changes associated with longitude (earlier chronotypes in the east within a time zone). A later time of sunrise was associated with a phase delay in circadian rhythmicity in studies conducted by Borisenkov in Russia (Borisenkov et al. 2010, 2012). Randler and Rahafar (2017), however, did not find a relationship between sunrise and M/E, and concluded that sunset is the most important predictor. Other factors such as altitude (Kentiba et al. 2018) and type of settlement (urban settings vs rural areas) (Borisenkov et al. 2010; Roenneberg and Merrow 2007) seem to have an impact on chronotype orientation as well.

Although there is representation of a variety of latitudes and longitudes in the research included in this review (Figure 3), 74% ($n = 64$) of the studies were conducted in latitudes from 30° to 60° North, and only a few closer to the equator (10%; $n = 9$ of the studies between 15° North and 15° South). Given the high variation in the number of hours of daylight in some countries, the time of the year should also be taken into consideration when interpreting results. We highlight the need to extend the research on chronotypes and performance in adolescents to more varied geographical settings, and encourage researchers to report the characteristics of as many of the forementioned aspects as possible in their work.

Study type

Considering the dynamic patterns of chronotype from childhood to adulthood and the important changes in cognitive and biological development during adolescence, it is surprising that only a couple of studies have examined the associations between circadian preferences and performance longitudinally (Biller et al. 2022; Scherrer and Preckel 2021). Biller et al. (2022) studied academic achievement in a flexible school start time over a 4-year period. They did not find a relationship between chronotypes and grades, and the advances in chronotype with flexible start times were not associated with improvements in grades. In contrast, Scherrer and Preckel (2021), reported positive correlations between morningness and GPA, and the opposite for evening tendencies in school-aged students. Interestingly, their study revealed a reciprocal relationship between circadian preference and academic achievement, with morningness predicting improvements in academic achievement and early academic achievement predicting lower eveningness over the 2-year study. Considering the lack of longitudinal research, this type of study is a priority for a better understanding of the direction of the relationships between chronotype and performance, and the causal processes that may be involved.

Evidence gaps and key research priorities

Our findings suggest that, while research in all aspects of performance has seen a growth in evidence, research into physical aspects is not as developed as other areas, thus constituting a priority for future studies. In addition, more longitudinal studies are needed to provide further insight into the strength and direction of the relationships between circadian preference and performance, as well as a better understanding of the changes over time. With the increasing interest in the multidimensional nature of circadian preference, and the development and validation of new questionnaires looking at different dimensions, it seems important to consider the assessment of circadian preference as a multidimensional construct, yet only a few studies on the topic have used such approach.

These research priorities, together with recommendations for future studies, have been highlighted in Table 3. Future reviews should also seek to undertake critical analysis and consider how to expand the recommendations made in this review, giving further insight into how research on this topic must be conducted. However, the current evidence is still in its infancy and with very marked gaps in some areas, hence not yet sufficient to allow such analysis or robust recommendations.

Strengths and limitations

This study constitutes the first scoping review on the topic. We have considered performance holistically, looking at all the performance outcomes available in the literature, and identifying some of the main research gaps. The review followed a well-established framework and a registered protocol, and it is in accordance with the PRISMA guidelines.

The search strategy for the review was designed to capture most of the current scientific evidence in relation to chronotypes and performance in adolescents,

Table 3. Identified research priorities and recommendations for future studies.

- Longitudinal studies
- Study of the associations between chronotype and physical performance
- Study of the associations between different aspects of performance in relation to chronotypes
- Performance measurements at several times during the day, including late sessions
- Study of the associations between chronotype and performance considering both chronological age and maturity status, as well as sex differences
- Clarity in the cut-off points criteria in chronotype assessment and the distribution of chronotypes in the samples
- Multidimensional assessment of chronotype
- Representation of a variety of circadian preferences, including extreme types
- Consideration of time since awakening
- Consideration of latitude and longitude, season/time of the year/day length, and other factors that may affect nonphotic entrainment (e.g., mealtimes, exercise)

and it was revised by several members of the team and an experienced research librarian. The use of a variety of databases and sources of grey literature, together with the combination of key terms identified in preliminary searches, allowed us to include a good representation of the research that has been conducted in the field. However, given the breadth of the topic and the difficulties in finding a good balance between sensitivity and specificity in search strategies, we are aware that we may have missed some studies. This limitation may be more evident in terms of finding grey literature and studies in languages other than English. To address this limitation, future work could look at including regional citation databases to cover specialist collections from a wider variety of regions. Nevertheless, given the small number of studies focusing on the areas we highlighted as key research priorities (e.g., need of longitudinal studies or studies on physical performance), it is unlikely that the missed studies would have filled such research gaps.

The searches were conducted in July and August 2021, and it is therefore possible that a number of studies on the topic were published after that. This was inevitable considering the time-consuming process of conducting a review and the resources available. However, our research team is familiar with the literature in the field and, while research has been undertaken in the last year (see, for example: Araújo et al. 2021; Fredrick et al. 2022; Jongte and Trivedi 2022; Sabaoui et al. 2022), the number of studies since the searches were conducted is not enough to fully address the identified research gaps. In this regard, our review creates a starting point for further research to build upon our findings.

To make the review feasible, it was not possible to have two reviewers complete the screening processes and data extraction for all records, but only conducted a 10% quality assessment at each of the stages as outlined in our protocol. A second reviewer checking only a random sample of the records is included as an acceptable approach for study selection in the updated PRISMA guidelines (Page et al. 2021), being more reliable than single screening. As per indication of the guidelines, we specified how many reviewers screened each record, whether they worked independently, and the tools used in the process. In our review, high level of concordance between reviewers suggests that it is unlikely that many studies were missing.

In line with the nature of scoping reviews, we did not conduct a critical appraisal. We also include sources which have not been peer reviewed. This approach allowed us to examine a large body of literature for a clear map of all available evidence and research gaps. However, findings of individual studies must be interpreted with caution. Small effect sizes were, for example, observed in some studies, which may limit the practical application of the results.

The age inclusion criterion was based on average and not on age range. While this means that some of the studies may have participants outside of the target population (10–19 years old), this is a more inclusive approach which prevented the loss of relevant data, and it is unlikely to considerably reduce the applicability of the findings.

Lastly, we included studies which assessed circadian preference or sleep phase, but not circadian phase measured through objective biological markers. Circadian preference reflects the individual differences in behaviors (preferred times for activities and sleep) and, although it is associated with the intrinsic circadian period of physiological markers, the two constructs are different (Lipnevich et al. 2017). Therefore, we deemed it appropriate to focus our review only on circadian preference and the associated behavioral aspects. In addition, the inclusion of both mechanisms would require extending the searches to other key words, which would yield an unmanageable number of records and would also make the comparability of the results difficult.

Despite these limitations, this scoping review offers an appropriate broad overview of the research on the topic, which can guide future studies and have applications in both educational and athletic settings.

Conclusion

This review constitutes an original summary of the literature available on chronotypes and performance in adolescence. In the last decade, there has been an increase in the number of studies in this area, with evidence suggesting that there are associations between circadian preferences and performance in this age group. Further research is needed to fully understand whether such associations are both direct and indirect, the direction and strength of the relationships, and the role of other factors such as sleep and learning motivation. This scoping review provides an overview of what has been studied in relation to the topic and highlights evidence gaps and key research priorities for future studies. Together with general recommendations, we emphasize the need for longitudinal research and further work on understudied aspects such as physical performance (Table 3). The review can also have practical implications for students, athletes, coaches, and educators to continue working towards a more informed educational and athletic practice.

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Data availability statement

Search strategies and data from the included studies can be found in Supplementary materials and Table 1 respectively.

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