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Time to learn: How chronotype impacts education

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Abstract: A growing body of literature has linked chronotype and sleep to school performance. Chronotype is under the control of the circadian clock and refers to sleep timing and diurnal preferences. Chronotype changes with age and is latest during adolescence, giving rise to a mismatch between the (late) circadian clock and the (early) school clock. In general, evening (late) chronotypes obtain lower grades. School performance is influenced by many other factors, such as motivation, intelligence, and conscientiousness. Some of these factors also relate to chronotype. The present paper reviews the literature on the relationship between chronotype and school performance, with the aim of suggesting hypotheses about the mechanisms behind this complex phenomenon and exploring solutions for an optimized school system. Based on the literature reviewed, we hypothesize that chronotype has both a direct and an indirect effect on school performance. The indirect effect is mediated by factors such as conscientiousness, learning/achieving motivation, mood, and alertness. In addition, time of day of testing plays an important role since the chronotype effect on grades is strongest in the morning and disappears in the afternoon. Strategies to decrease the mismatch between the adolescent circadian clock and the school clock could involve light interventions to advance the students' sleep timing, delays in school starting times, and rearrangements of test schedules (tests later in the day).

Keywords: chronotype; diurnal preference; education; school performance; sleep

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Education plays an important role in determining future career opportunities (French, Homer, Popovici, & Robins, 2015; Ma, Pender, & Welch, 2016). School achievements (e.g., grades) are often used as selection criteria for admission to universities and are also among the best predictors for academic success after high school (Geiser & Santelices, 2007). Many factors influence school achievements. Intelligence, academic motivation, and conscientiousness are examples of individual characteristics relevant for obtaining good grades (Bratko, Chamorro-Premuzic, & Saks, 2006; Deary, Strand, Smith, & Fernandes, 2007; Fortier, Vallerand, & Guay, 1995). In addition, many other factors not under the direct control of students, such as socioeconomic status, parental involvement, and quality of the teachers, influence how they perform in school (Juang & Silbereisen, 2002; Pokropek, Borgonovi, & Jakubowski, 2015; Rockoff, 2004). Sleep and

chronotype (a function of the circadian clock) are examples of biological factors that contribute to success in school. In this review, we discuss the influence of chronotype on school achievements in order to develop hypotheses concerning the mechanisms behind this phenomenon.

What is chronotype and how is it measured?

The term “chronotype” has been used in the literature in relation to both sleep timing (Roenneberg, Wirz-Justice, & Merrow, 2003) and to the psychological construct “diurnal preference” (Horne & Östberg, 1976). In both cases, chronotype is assessed with simple questionnaires (discussed below). Depending on the questionnaire used, chronotype is expressed as a continuous variable (e.g., the Munich ChronoType Questionnaire [MCTQ]; Roenneberg et al., 2003)

or as a categorical variable (e.g., the Morningness–Eveningness Questionnaire [MEQ]; Horne & Östberg, 1976). Although chronotype can be assessed and expressed in different ways, there is consensus that chronotype is under the control of the circadian clock. The circadian clock confers rhythmicity on many biological processes, from molecules to behaviors, and uses light as the main zeitgeber (time cue) to entrain (synchronize) behavior to the external light–dark cycle (Roenneberg & Merrow, 2007; Roenneberg, Kumar, & Merrow, 2007). The variability in the light landscape, as well as in the biological and genetic background of individual circadian clocks, leads to a wide distribution of phases of entrainment to the external light–dark cycle. Chronotype (at least using the MCTQ) is an estimate of an individual phase of entrainment via subjective assessment of sleep timing.

In this section, we explain how sleep timing is regulated, how sleep and chronotype can be measured with different questionnaires, and that chronotype is later during adolescence, a particularly relevant finding with respect to school performance.

The regulation of sleep

According to the two-process model, the timing and consolidation of sleep is regulated by a circadian and a homeostatic process (Borbély, 1982; Daan, Beersma, & Borbély, 1984). Sleep pressure (homeostatic process) increases during wakefulness and is dissipated during sleep. The circadian clock promotes wakefulness during the day and sleep during the night (in diurnal animals). The likelihood of falling asleep increases when sleep pressure is high and when the circadian clock stops promoting wakefulness and starts promoting sleep. The two-process model predicts various sleep characteristics of properties that are interesting for society and behavior. For instance, the model predicts that sleep duration is shorter when sleep occurs outside the circadian window for sleep, thus predestining shift workers—or those that need an alarm clock to match biological and social clocks—to regular sleep deprivation. Experimental data collected before and after the model was proposed support this observation and other predictions, such as REM sleep being highest when the end of the sleep episode coincides with the end of the circadian sleep window (Åkerstedt & Gillberg, 1981; Czeisler, Weitzman, Moore-Ede, Zimmerman, & Knauer, 1980; Dijk & Czeisler, 1995). The two-process model has been amended by various researchers over the years to reflect real life observations, for instance age-related

changes in sleep (Borbély & Achermann, 1999; Phillips, Chen, & Robinson, 2010; Skeldon, Derks, & Dijk, 2016).

Estimating chronotype with questionnaires

The timing of sleep is thus viewed as a circadian-clock-regulated trait. Sleep timing is subjectively assessed via the MCTQ (Roenneberg et al., 2003). This short questionnaire asks about behavior separately on school (or work) days and on school-free (or work-free) days. Chronotype is calculated from the MCTQ as the midpoint of sleep on school-/work-free days (MSF), corrected for sleep debt accumulated on school/workdays (MSF_{sc}). Chronotype is expressed as local clock time and ranges from early (early midpoint of sleep) to late (late midpoint of sleep) chronotypes, with most individuals hovering in the middle, forming almost a normal distribution. Unlike the MCTQ, which derives chronotype from sleep timing on school/work-free days, the MEQ assesses chronotype based on diurnal preferences (e.g., preferred time of day to perform physical and mental work; Horne & Östberg, 1976). With this questionnaire, chronotype is categorized as a score (range: 16–86), with high numbers corresponding to morning types (59 and above), low numbers corresponding to evening types (41 and below), and numbers between 42 and 58 corresponding to intermediate types. In 1993, an adapted version of the MEQ was developed for children and adolescents: the Morningness–Eveningness Scale for Children (MES-C; Carskadon, Vieira, & Acebo, 1993). There are also other questionnaires assessing chronotype, such as the Composite Scale of Morningness (CSM; Smith, Reilly, & Midkiff, 1989) and the Lark–Owl Chronotype Indicator (R. D. Roberts, 1998). The CSM combines two questionnaires assessing diurnal preferences: the Horne and Östberg (MEQ; 1976) and the Torsvall and Åkerstedt (1980) scales (the CSM, MEQ, and MCTQ are reviewed in Levandovski, Sasso, & Hidalgo, 2013). The Lark–Owl Chronotype Indicator also measures morningness and eveningness, but on the basis of a two-dimensional conceptualization.

MCTQ and MEQ answers are generally highly correlated ($r = -.73$; Zavada, Gordijn, Beersma, Daan, & Roenneberg, 2005). We prefer to use the MCTQ, as it assigns a putative internal clock time rather than a general score, which is a more useful feature for trying to understand the interaction of internal and external time, for example. Concerning validity of the two instruments, chronotype assessed via MCTQ and MEQ also correlates with dim-light melatonin

onset (DLMO; MEQ: $r = -.70$; MCTQ: $r = .68$; Kantermann, Sung, & Burgess, 2015). DLMO is considered a physiological measure of phase of entrainment of the circadian clock (Arendt, 2006; Klerman, Gershengorn, Duffy, & Kronauer, 2002). The levels of the hormone melatonin rise in the evening, are high during the night, and low during the day. This 24-h rhythm in melatonin production and secretion is under the control of the circadian clock and is stable and robust against the influence of external factors (except for light, which directly suppresses melatonin). Melatonin concentrations are measured in saliva, urine, or plasma using several methods. However, given that these tend to be costly, estimating chronotype or entrained phase with questionnaires permits larger-scale studies. The MCTQ online database currently contains well over 200,000 entries.

To the best of our knowledge, there are no studies that have correlated DLMO to school achievements, while many studies have investigated the relationship between chronotype and school performance.

Adolescents have a late chronotype

The decisive years when students are sorted into those that will continue to higher education, such as university, and those that will cease their formal education generally coincide with adolescence. Several studies have reported that adolescents sleep longer and later than adults (Crowley et al., 2014; Klerman & Dijk, 2008; Roenneberg et al., 2004). The reasons for a delay in sleep timing (and chronotype) in adolescents have already been reviewed elsewhere (Crowley, Acebo, & Carskadon, 2007; Hagenauer, Perryman, Lee, & Carskadon, 2009; Jenni, Achermann, & Carskadon, 2005). A delay in chronotype is observed also in animals (some mammals, such as rhesus monkeys, and laboratory rats and mice), suggesting that systematic changes occur during puberty that delay the circadian clock as opposed to purely societal structures (Hagenauer et al., 2009).

One explanation for a late chronotype or phase of entrainment in adolescence could lie in (as yet unidentified) hormonal changes regulating downstream physiologies to change chronotype. An alternative explanation comes from an exploration of light sensitivity in adolescence. Time-of-day-specific or general changes in sensitivity to light could both lead to a change in entrained phase. A rule of thumb is that exposure to light during the end of the subjective (internal) night induces phase advances, while exposure to light during the beginning of the subjective (internal) night induces phase delays (Khalsa, Jewett, Cajochen, &

Czeisler, 2003). Therefore, a decreased sensitivity to light in the morning and an increased sensitivity to light in the evening would lead to a delayed phase of entrainment. In a recent study, older (late/post-pubertal stage) adolescents were found to be less sensitive to light both in the morning and in the evening when compared to younger (early/mid-pubertal stage) adolescents (500 lx morning light, $p = .06$; 500 lx evening light, $p < .05$; Crowley, Cain, Burns, Acebo, & Carskadon, 2015). An overall decrease in sensitivity to light seems therefore related to a delayed phase of entrainment in adolescents, rather than an increase in sensitivity to light in the evening hours. In line with this, the strength of the zeitgeber is also related to phase of entrainment: Individuals with less daily light exposure show in general a later phase of entrainment (Roenneberg & Merrow, 2007; Wright et al., 2013). Interestingly, this correlation was not found in adolescents (15–20 years old), suggesting again that this age group could be in general less sensitive to light (Roenneberg et al., 2015).

In addition to physiological changes relevant for the circadian timing system, there is evidence that the homeostatic process is altered in adolescents. The build-up of sleep pressure is slower in older adolescents, allowing them to stay awake later (Jenni et al., 2005; Taylor, Jenni, Acebo, & Carskadon, 2005). Exposure to additional evening light (not necessarily an increased sensitivity) would lead to a later entrained phase (Crowley et al., 2015). The use of electronic media before going to bed, very common in this age group, has been associated with delayed and disturbed sleep (Cain & Gradisar, 2010; Munezawa et al., 2011; Van den Bulck, 2004). General difficulties with sleeping and morning tiredness have also been reported in adolescents who consume high doses of caffeine (Orbeta, Overpeck, Ramcharan, Kogan, & Ledsky, 2006).

Psychosocial factors, such as an increased need of independency, could also contribute in influencing sleep timing in adolescents. For instance, when parents dictate bedtimes, they are earlier (Short et al., 2011). This could also lead to earlier entrained phase via restriction of evening/nighttime light exposure.

In conclusion, both modifications in the circadian and in the homeostatic processes, such as altered sensitivity to light and to sleep pressure, may contribute to a delay in sleep timing. In addition, the consumption of caffeine, the use of electronic media in the evening, and self-selected bedtimes are examples of other factors that can exacerbate this phenomenon.

Chronotype and school performance

The influence of chronotype on school performance has been extensively studied during the past 20 years. Although different chronotype questionnaires have been used, consistent findings about late (evening) types obtaining lower school achievements have been reported (Arbabi, Vollmer, Dörfler, & Randler, 2015; Borisenkov, Perminova, & Kosova, 2010; Díaz-Morales & Escribano, 2013; Giannotti, Cortesi, Sebastiani, & Ottaviano, 2002; Kolomeichuk, Randler, Shabalina, Fradkova, & Borisenkov, 2016; Preckel et al., 2013; Rahafar, Maghsudloo, Farhangnia, Vollmer, & Randler, 2016; Randler & Frech, 2006, 2009; Roeser, Schlarb, & Kübler, 2013; Short, Gradisar, Lack, & Wright, 2013; van der Vinne et al., 2015; Vollmer, Pötsch, & Randler, 2013; Warner, Murray, & Meyer, 2008). However, the mechanism(s) behind this phenomenon are still unclear. The influence of chronotype on school performance could take place during the learning (at school and at home) and/or the evaluation phase or both. In addition, the effect of chronotype on school achievements could be direct and/or could be mediated by other factors that are relevant for performance.

Lower school performance in late/evening chronotypes

Several studies have used the MEQ or the adapted versions of the MEQ for children and adolescents (MESQ; Carskadon et al., 1993; and Pupils' MEQ; Randler & Frech, 2006) to assess the effect of chronotype on official or self-reported grades in high school students (Díaz-Morales & Escribano, 2013; Escribano, Díaz-Morales, Delgado, & Collado, 2012; Giannotti et al., 2002; Preckel et al., 2013; Randler & Frech, 2009). In all of these studies, evening types obtained lower grades compared to morning types. The MEQ score is also correlated with sleep duration, age, and sex: Adolescents with a stronger preference for eveningness usually sleep shorter on school nights, are older, and are more likely to be male (Owens, Dearth-Wesley, Lewin, Gioia, & Whitaker, 2016; Tonetti, Fabbri, & Natale, 2008). When controlling for total sleep time, sex, and age, evening types still obtained lower grades (Díaz-Morales & Escribano, 2013; Escribano et al., 2012; Randler & Frech, 2009). Giannotti et al. (2002) performed a regression analysis to assess the impact of 12 independent variables (variables related to substance use, emotional aspects, circadian

preference, demographics, and sleep) on school performance. The authors found that evening preference, odds ratio (OR) 1.6, 95% confidence interval (CI) [1.02, 2.56], was among the predictors for poor school performance together with emotional problems, OR 1.04, 95% CI [1.01, 1.07], substance use, OR 1.1, 95% CI [1.03, 1.21], and sex, female: OR 0.47, 95% CI [0.26, 0.84]. In another study, eveningness (measured with the Lark–Owl Chronotype Indicator; R. D. Roberts, 1998) was found to be negatively correlated to self-reported final school year grades when controlling for other factors relevant for school achievements, such as cognitive ability, conscientiousness, achievement motivation, need for cognition, and daytime sleepiness. Eveningness explained an additional 2.5% of the variance in overall school grades (Preckel et al., 2013). The influence of circadian preference was also shown on the final high school exam (often used as admission criterion to universities), with evening types scoring lower compared to morning types ($r = .23$, $p = .008$; Randler & Frech, 2006).

Studies that have assessed chronotype using other questionnaires, such as the MCTQ and the CSM (Smith et al., 1989), found the same chronotype effect on grades, with late chronotypes obtaining lower grades compared to early chronotypes (Borisenkov et al., 2010; Kolomeichuk et al., 2016; van der Vinne et al., 2015; Vollmer et al., 2013).

Two recent meta-analyses analyzed the relationship between chronotype and school/academic performance in high school and university students (Preckel, Lipnevich, Schneider, & Roberts, 2011; Tonetti, Natale, & Randler, 2015). Preckel et al. (2011) performed two separate meta-analyses to explore the relationship between morningness and academic achievements, and eveningness and academic achievements. They found that morningness was positively ($r = .16$, $p < .001$) associated with academic achievements, while eveningness was negatively ($r = -.14$, $p < .001$) associated with academic achievements. The effect sizes were small explaining about 2% of the variance in academic achievements. Similarly, the meta-analysis of Tonetti, Natale, and Randler (2015) showed that evening types have worse academic achievements (small effect size of 0.143, CI [0.129, 0.156]). A separate analysis for studies done in high school and university students revealed that the effect of chronotype was stronger in high school students (high school students: 0.166, CI [0.127, 0.206]; university students: 0.121, CI [0.080, 0.163]).

Taken together, several studies that have assessed chronotype, while controlling for different factors, have found that evening (late) types obtain lower achievements at high school. However, the strength of the relationship between chronotype and school achievements can vary between studies depending on the covariates assessed. For instance, Díaz-Morales and Escribano (2015) reported that the MESC score in their sample of high school students was related to school achievements only when controlling for age ($r = .09$, $p < .05$); the significant correlation disappeared when other sleep-related variables, such as time in bed, were added in a multivariate linear regression model (females: $\beta = .00$, $p > .05$; males: $\beta = .06$, $p > .05$). Especially when considering both chronotype and sleep duration, it is difficult to disentangle the effects of these two variables on school performance. Chronotype is tightly linked to sleep duration, with late chronotypes in general sleeping shorter on school/work days (Roenneberg, Kuehnle, et al., 2007). Although the negative effect of short sleep duration on school achievements has been described in many reviews, it is not clear how much of this effect is related to being a late chronotype and how much to sleeping too little (Curcio, Ferrara, & De Gennaro, 2006; Dewald, Meijer, Oort, Kerkhof, & Bögels, 2010; Taras & Potts-Datema, 2005; Wolfson & Carskadon, 2003). Borisenkov et al. (2010) reported a twofold stronger effect of chronotype on school grades relative to sleep duration (chronotype: $\eta^2 = .022$; sleep duration: $\eta^2 = .013$), suggesting that chronotype should be included in future research about the effect of sleep on school performance.

To further elucidate the influence of chronotype on school performance, we next review the relationship between chronotype and individual/personality factors relevant for school performance.

Chronotype and individual/personality factors relevant for school performance

In addition to chronotype, there are several factors that influence school performance, and some of these factors have also been found to be associated with chronotype. For instance, conscientiousness (being organized, self-disciplined, and goal-oriented) is a personality trait that is positively related to both morningness and high school achievements (Bratko et al., 2006; Randler, 2008; Tonetti, Fabbri, & Natale, 2009). Two recent studies that investigated both chronotype and conscientiousness in the context of school performance found that the chronotype effect on

school grades was significant only when conscientiousness was analyzed as a mediating factor, suggesting that chronotype influences conscientiousness, which in turn impacts grades (Arbabi et al., 2015; Rahafar et al., 2016).

Roeser et al. (2013) explored the relationship between chronotype, learning/achieving motivation, sleepiness, and school performance. Similarly, they did not find a direct influence of chronotype on school performance, and they concluded that chronotype was likely to influence school performance by increasing sleepiness and decreasing learning/achieving motivation in evening types. In line with this study, Escribano and Díaz-Morales (2016) also found that morning types show higher learning and performance goals, and that these goals are positively associated with school performance. This association was found to be stronger in evening types, suggesting again that the chronotype effect on grades could be mediated by other factors, such as achievement motivation.

Mood, daytime functioning, and alertness are also important for obtaining good grades and are influenced by chronotype (Short et al., 2013; Vollmer et al., 2013; Warner et al., 2008). For instance, Short et al. (2013) showed that evening types have lower sleep quality, increased depressed mood, and decreased alertness. In the same study, students with an evening chronotype and lower sleep quality reported lower grades, and this relationship was mediated by depressed mood.

Finally, intelligence is one of the strongest predictors for school performance (Arbabi et al., 2015; Deary et al., 2007). Despite this, only a few studies have investigated a possible relationship between chronotype and intelligence in adolescents with contradicting results. Arbabi et al. (2015) found that morningness was positively related to intelligence in a sample of 10-year-old children. In older students already attending university, this relationship was reversed with evening types scoring higher on a standardized test for admission to university that correlates with a measure of general intelligence (Piffer, Ponzi, Sapienza, Zingales, & Maestripieri, 2014). In another study, verbal IQ scores obtained during adolescence were shown to be a predictor of circadian preference, with more intelligent students preferring eveningness as adults (Kanazawa & Perina, 2009). Although not in the context of school performance, the study of Goldstein, Hahn, Hasher, Wiprzycka, and Zelazo (2007) specifically investigated the relationship between chronotype and intelligence, taking into account time of day. Subtests of the

Wechsler Intelligence Scale for Children III (1991) were administered to assess both fluid (reasoning, logic, abstract thinking) and crystallized (vocabulary, general knowledge) intelligence at two times of day (morning and afternoon). Only for fluid intelligence was there a significant interaction effect between chronotype and time of day, with morning types obtaining higher scores in the morning and evening types obtaining higher scores in the afternoon. The main effect of chronotype on intelligence scores was not significant, suggesting that chronotype is not associated with intelligence per se, but that the performance in intelligence tests depends on the interaction between chronotype and time of day of testing. In line with these results, we also found no correlation between chronotype and IQ scores (assessed with the Nederlandse Intelligentietest voor Onderwijsniveau, a Dutch intelligence test used in schools) in 97 high school students (54 females, mean age 12.78 years \pm 1.03 *SD*) when controlling for age and sex (Figure 1), and when not controlling for time of day (test times were unknown; procedure approved by the Medical Ethical Committee of the University Medical Centre of Groningen, the Netherlands, and written informed consent for data utilization was obtained from the head of the school).

In conclusion, there is evidence both for a direct and for an indirect effect of chronotype on grades mediated by other relevant factors for school performance, such as conscientiousness, learning/achieving motivation, mood, and

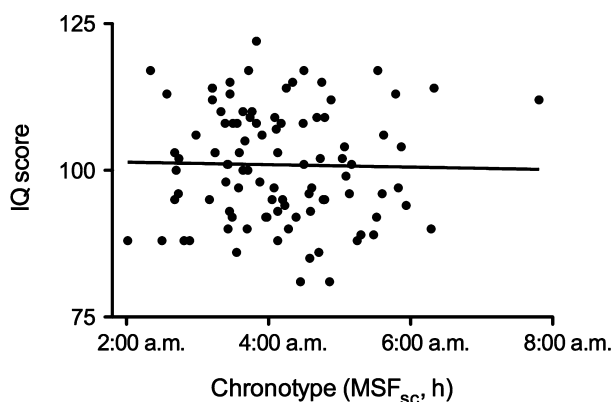


Figure 1. Relationship between chronotype (assessed with the Munich ChronoType Questionnaire [MCTQ]) and IQ score (assessed with the Nederlandse Intelligentietest voor Onderwijsniveau) in 97 high school students (54 females, mean age 12.78 years \pm 1.03 *SD*). The correlation between chronotype and IQ score was tested with a linear regression model with age and sex as covariates. Chronotype and IQ score were not significantly correlated ($\beta = .8901$, $t(93) = 0.844$, $p = .4006$). MSF_{sc} = mid-point of sleep on school-free days.

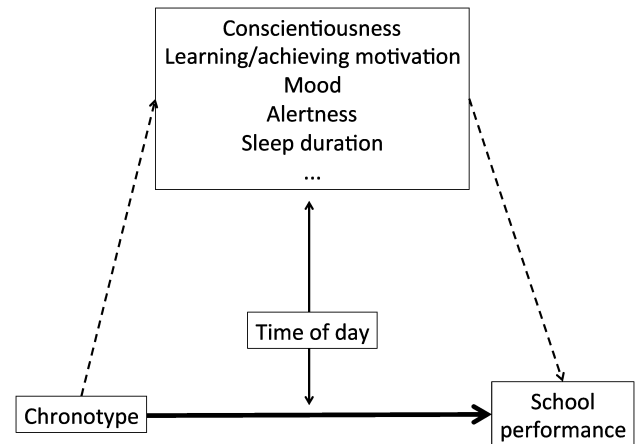


Figure 2. Chronotype and school performance. Chronotype can have both a direct effect (bold solid line) and an indirect effect (dashed lines) on school performance. The direct effect depends on time of day, with time of day acting as moderator variable of the relationship between chronotype and school performance. The indirect effect of chronotype on school performance is mediated by other factors, such as conscientiousness, learning/achieving motivation, mood, alertness, and sleep duration. Chronotype influences these factors, which, in turn, impact school performance. For instance, late chronotypes have lower levels of conscientiousness, and lower levels of conscientiousness are associated with lower school performance. Finally, time of day also influences some of these other factors, such as mood and alertness.

alertness. Figure 2 summarizes this complex effect of chronotype on grades.

Chronotype, time of day, and school performance

In addition to the factors previously described, time of day should also be taken into account when looking at the effect of chronotype on grades. It is well known that performance at numerous levels shows changes with time of day and is clock-regulated. Thus, it is reasonable to hypothesize that the cognitive abilities of different chronotypes vary accordingly with time of day. Several studies have used educational research to investigate the idea.

The first observations that school times might not be optimal for some students were reported in the early 1980s. Both test results and truancy were found to improve when school times were matched to the students' circadian preference (Lynch, 1981; Virostko, 1983). In addition, students who reported feeling more alert and performing better at school in the morning obtained a higher grade-point average (Biggers, 1980). In 1999, Callan found that students with a preference for learning in the morning scored better in an algebra test compared to students with a preference for learning in the afternoon and in the evening. Only

recently, a few studies have linked chronotype, time of day, and school performance in adolescents. We showed that the chronotype-effect on grades depends on time of day, with late chronotypes underperforming early chronotypes in the morning (8:15 a.m.–12:15 p.m.), but not in the early afternoon (12:45–3:00 p.m.; van der Vinne et al., 2015). Similarly, Itzek-Greulich, Randler, and Vollmer (2016) found a chronotype effect on a chemistry test for students who had attended the course in the morning, with early chronotypes performing better compared with late chronotypes. The association between chronotype and test results was not significant for students who had attended the course in the afternoon. If we assume that early and late chronotypes only differ in their phase of entrainment, these results could be explained with late chronotypes being tested when their peak capacity in cognitive performance has not yet been reached (Figure 3).

Based on both these findings and also on other results about time-of-day fluctuations in cognitive abilities depending on chronotype, more studies about the effect of chronotype and time of day on school performance are warranted (Escribano & Díaz-Morales, 2014; Goldstein et al., 2007; Hahn et al., 2012; van der Heijden, de Sonnevile, & Althaus, 2010).

How to remove the chronotype “handicap”

During the past decades, several studies have demonstrated that the current school starting times challenge the sleep and performance of high school students, especially students with late chronotypes. The studies reviewed here show that the influence of chronotype on grades is complex. In general, late chronotypes obtain lower grades, and this can negatively influence their future academic careers (e.g., access to university). Although the effect sizes reported are small, a significant association between chronotype and school achievements has been reported in many studies, also when controlling for confounding factors, such as sex, age, and sleep duration. There is evidence for a direct effect of chronotype on grades, but also for an indirect effect mediated by other factors relevant for school performance, such as conscientiousness, learning/achieving motivation, mood, and alertness. In addition, time of day of testing seems to play an important role acting as a moderator variable of the relationship between chronotype and school grades. Since the poor school performance of late

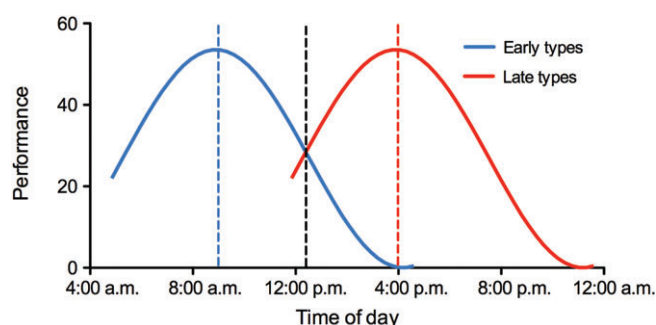


Figure 3. Interaction effect between chronotype and time of day on school grades based on the daily variation in (cognitive) performance in early (blue curve) and late (red curve) chronotypes. Here, we assume that the variation in performance has the same shape for early and late chronotypes, but the peak in performance is shifted to a later time point in the day for late chronotypes. The vertical dashed lines indicate when early (blue) and late (red) chronotypes would perform best during an examination. In this particular example, early chronotypes would perform best around 9:00 a.m., late chronotypes would perform best around 4:00 p.m., and no difference between chronotypes (black dashed line) would be observed around 12:30 p.m. [Color figure can be viewed at wileyonlinelibrary.com]

chronotypes arises from a mismatch between the circadian and the social clocks, the efficacy of interventions aiming to reduce this mismatch should be tested in experimental studies (Figure 4).

Advancing sleep timing in adolescents (especially late chronotypes)

Interventions to advance sleep timing in adolescents, resulting in longer and improved sleep, could be implemented at school. Several sleep hygiene programs have been developed and their efficacy has been tested in randomized, controlled studies. Depending on the specific program, different positive outcomes have been achieved, such as longer sleep duration, earlier bed times, and reduced discrepancy between sleep timing on weekdays and on weekends (Kira, Maddison, Hull, Blunden, & Olds, 2014; Moseley & Gradisar, 2009; Wolfson, Harkins, Johnson, & Marco, 2015). However, the observed changes did not always concern all students, and often disappeared at the last follow-up assessments.

The modulation of light exposure at specific times of day could help to advance the late circadian clocks of adolescents. As previously described, increased morning light and decreased evening light are two potentially effective interventions. Although the response of the circadian system to light exposure at different times of day is quite well described, only a few studies have tested the effectiveness of light interventions to advance phase of entrainment in

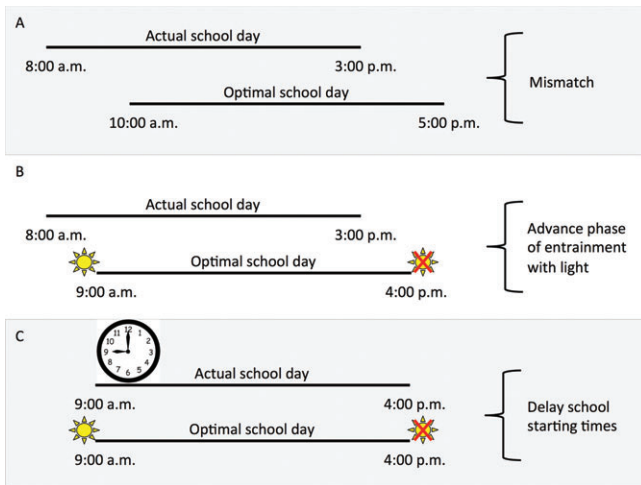


Figure 4. Strategies to optimize the school day for adolescents. (A) The early school starting times and the late circadian clock of adolescents give rise to a mismatch that has consequences for sleep, and for performance of the students. (B) One way to decrease this mismatch is to apply interventions to advance sleep timing in adolescents, such as increasing light exposure in the morning and/or decreasing light exposure in the evening. (C) In addition to advancing the phase/chronotype of students using light, as in Panel B, school starting times could be delayed, thus decreasing the mismatch using social and biological considerations. [Color figure can be viewed at wileyonlinelibrary.com]

adolescents. Concerning morning light, 2 weeks of white light exposure in the classroom (between 8:10 a.m. and 9:43 a.m.) on school days were not enough to shift sleep timing in high school students (Hansen, Janssen, Schiff, Zee, & Dubocovich, 2005). Similarly, 20-min exposure to a dawn simulator before awakening did not affect sleep timing in adolescents (Tonetti, Fabbri, et al., 2015). One hour of short-wavelength light exposure on weekend days upon awakening was also not effective in counteracting the delay in dim-light melatonin onset over the weekend (compared to weekdays) in adolescents (Crowley & Carskadon, 2010). Although these results suggest that morning light might not be effective in advancing sleep of adolescents, it is possible that the timing and intensity of light exposure were not optimal. It is also possible that adolescents are less sensitive to light as a zeitgeber (Roenneberg et al., 2015).

The use of technology in the evening (computers, phones, video games) with, as a consequence, an increased exposure to evening (blue) light was listed as a risk factor for adolescent sleep in a recent meta-analysis (Bartel, Gradisar, & Williamson, 2015). A simple intervention, such as wearing blue-light-blocking glasses in the evening, was shown to reduce the suppression of melatonin associated with exposure to light, and to decrease alertness before bedtime (van der Lely et al., 2015). Similar results in terms

of decreased alertness were found when comparing the use of a bright screen with a dim screen 1 hr before bedtime (Heath et al., 2014). In both studies, no significant changes in sleep variables (e.g., sleep onset latency) were found, although several studies have shown an association between the use of media in the evening and sleep disturbances (Cain & Gradisar, 2010; Munezawa et al., 2011; Van den Bulck, 2004). More research is needed to establish guidelines about the evening use of electronic devices in adolescents in relation to their sleep.

Other solutions to improve sleep in adolescents could involve physical activity. A recent study showed that running for 30 min in the morning on a school day (for 3 weeks) shortened sleep latency, improved sleep quality, and increased time spent in deep sleep (Kalak et al., 2012). In this study, morning light exposure was controlled for, suggesting that the positive effect on sleep was a result of morning physical activity.

Taken together, although there is evidence for a delayed, short, and disturbed sleep in adolescents, there are too few studies testing interventions to advance sleep, and to increase sleep duration and quality in adolescents. The light interventions previously described are supposed to influence the phase of entrainment of the circadian clock. The homeostatic process, also involved in the regulation of sleep, has received less attention, although one of the hypotheses for a delay in sleep timing in adolescents is a decreased susceptibility to the build-up of sleep pressure during the day (Hagenauer et al., 2009; Jenni et al., 2005). Future research should extensively test different light interventions to advance sleep timing in adolescents and try to elucidate which intensities and which type of light (e.g., color) to apply/avoid at particular times of day. This should be specifically tested in adolescents since their sensitivity to light might be different from that of adults (Roenneberg et al., 2015). In addition, interventions that could affect sleep pressure should also be developed and tested.

Delaying school starting times

In addition to strategies to advance sleep timing, another solution to improve school performance would be to delay school starting times. Not only late chronotypes but also the majority of high school students would benefit from a delay in school starting times. In fact, several studies have reported worrying statistics about sleep duration (on a typical school night) in adolescents, which is shorter than the recommended 9 hr of sleep for about 80–90% of the

students (Basch, Basch, Ruggles, & Rajan, 2014; Gibson et al., 2006; R. E. Roberts, Roberts, & Duong, 2009). Interestingly, already in 1913, Terman and Hocking hypothesized that the longer sleep duration observed in American compared to German adolescents was in part due to a later school starting time in the United States (United States at 9:00 a.m. vs. Germany at 8:00 a.m.). Recently, Wolfson and Carskadon (2005) published a survey about the factors influencing high school starting times. Urban schools and schools with larger enrollments tended to start earlier. The socioeconomic status of the parents was also found to be associated with school starting times, with higher status related to earlier starting times. Finally, school starting times correlated with (trivial) factors such as how bus schedules were organized.

In the past decades, several schools have delayed their school starting times. There is increasing evidence of positive outcomes in terms of mood, sleep, daytime sleepiness, school attendance, and school performance after a delay in school starting times was introduced (Boergers, Gable, & Owens, 2014; Carrell, Maghakian, & West, 2011; Owens, Belon, & Moss, 2010). For a complete overview of schools that have successfully implemented later school schedules, we suggest the work of Owens, Droblich, Baylor, and Lewin (2014) and that of Wahlstrom et al. (2014). Nevertheless, more longitudinal studies monitoring the effects of delayed school starting times are needed. For instance, a recent study showed that a 45-min delay in school starting times was associated with a 20-min gain in sleep duration (within the first 6 months after the change) that was lost after 1 year (Thacher & Onyiah, 2016).

Two other studies have assessed differences in sleep between high school students attending morning or afternoon lectures, taking chronotype into account (Koscec, Radosevic-Vidacek, & Bakotic, 2013; Martin, Gaudreault, Perron, & Laberge, 2016). In general, sleep duration was significantly longer for students attending the afternoon shifts. This was observed even in morning types who also reported higher sleepiness during the morning shift (Martin et al., 2016). Although the sample of students was small ($N = 57$), the authors found no significant difference in grades between students attending the morning and the afternoon shift, and overall evening types did not obtain lower grades compared to morning types. These studies suggest that early school starting times (7:40 a.m. and 8:00 a.m.) might have detrimental effects even for students classified as “morning types” on the MEQ scale.

Some schools, for instance in the Netherlands, have also experimented with flexible starting times: Core subjects are taught in the middle of the day, while other school activities are offered earlier in the morning or later in the afternoon, and the students can choose their preferred time for attending these activities (<http://www.deschool.nl>).

More studies are needed to assess whether students' sleep and performance could benefit from such a flexible school system. In a recent study, the widely described chronotype effect on grades was not found among online-learning students, suggesting again that self-selected sleep and learning schedules could improve students' performance (Horzum, Önder, & Beşoluk, 2014).

Changing school schedules

If a delay in school starting times is not feasible, another solution could involve a rearrangement of school schedules. For instance, the finding that the chronotype effect on grades depends on time of day of testing advocates that tests should be scheduled later in the day (Itzke-Greulich et al., 2016; van der Vinne et al., 2015). Already in 1995, Callan suggested that an important test for access to college, such as the Scholastic Aptitude Test (SAT), should be offered at different times of day (and not only at 8:30 a.m.) in order to avoid discriminating against students according to their time-of-day preferences in learning. Considering time of day is also essential for scheduling the different school subjects within the school day. As reviewed by Wile and Shouppe (2011), there is a time-of-day dependency in specific cognitive abilities necessary for different school subjects, and this is likely to vary between chronotypes. Although more research is needed to establish the optimal time of day for teaching and testing, many schools have already begun changing their schedules.

Conclusion

To allow late chronotypes to perform at their best, schools could take advantage of the recent findings reviewed here. For instance, late chronotypes seem to particularly suffer in specific areas related to learning and school performance, such as conscientiousness and motivation (Arbabi et al., 2015; Rahafar et al., 2016; Roeser et al., 2013). With the use of simple questionnaires, such as the MCTQ and the MEQ, late chronotypes could be first identified, and then interventions could be developed to increase their levels of

conscientiousness and motivation, with a possible positive outcome in terms of school performance.

Many studies are still needed to fully understand the circadian system of adolescents, to unravel the mechanisms behind the effects of chronotype on school performance, and to develop effective strategies to improve school performance in late chronotypes. Nonetheless, the iterative exchange of data between schools and scientific researchers is setting up the basis for a more fair school system for all students, independent of their chronotype.

Disclosure of conflict of interest

The authors declare that there are no conflicts of interest.

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