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Sleep and academic performance: considering amount, quality and timing

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Evidence has shown that sleep plays a key role in cognitive functioning, and here the specific importance for memory consolidation in the context of academic performance is discussed. As school years are also a turning point into defining one's chronotype and general sleep habits, it is vital that schools and universities offer a flexible structure for students to be able to develop healthy sleep practices allowing for the very much needed space for memory consolidation.

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Introduction

Sleep is essential for cognitive functioning, and that how good our sleep is depends not only on the length and quality, but also on the timing relative to our natural sleep onsets (chronotypes). Our chronotypes are influenced by gender and more importantly age, that is, exactly when we need to learn the most (high-school/university) we tend to display later chronotypes [1]; however current school and university timings favor early chronotypes; a discrepancy that influences academic performance. In this review we will summarize general background on sleep and cognition as well as highlight crucial associations between sleep and academic performance in particular.

Sleep as fluctuations

Sleep is a complex process that despite diminished behavioral response to stimuli, presents with an active brain. During sleep neurons display up and down regulation of firing that enables a large variety of functions from general homeostasis to specific memory consolidation [2,3]. Such alternation of firing rates is also related to two distinguishable sleep stages known in mammals: Non-Rapid Eye Movement Sleep (NREM) and Rapid Eye Movement Sleep (REM). These stages alternate during the main resting period and serve as hallmarks for the study of sleep, revealing an internal homeostasis and regulation (see Figure 1a).

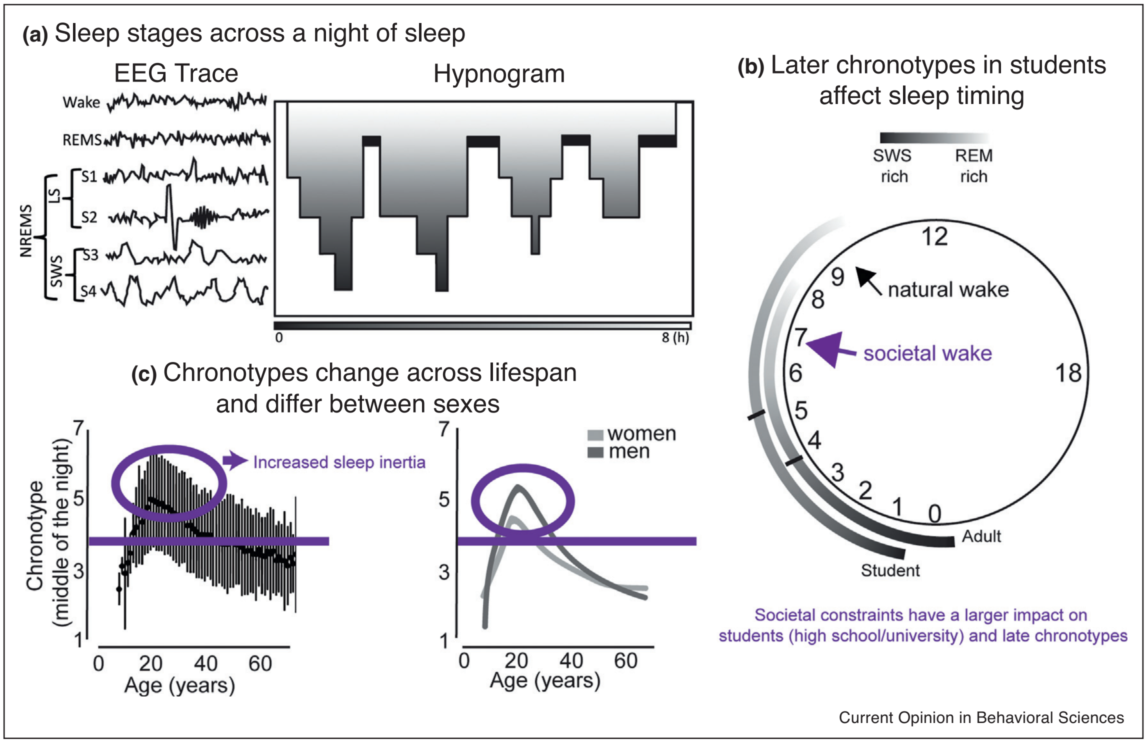
Sleep regulation is a combination of both internal clocks and external regulators [2,3], as well as homeostatic pressure of general sleep need. Under ideal circumstances, both forces are in equilibrium allowing the individual to do the right thing at the right time [4]. Nevertheless, humans display marked preferences for their sleep times and such preferences give origin to the chronotypes [5]. Chronotypes vary with age and sex (Figure 1b and c) and depend on cultural factors such as type of productive activity and biological ones: geographical location and concurrent sunlight exposure [6•]. On occasions, external cues of timing and internal needs are greatly misaligned; examples include the jet-lag effect resulting from moving across time zones or social-jet-lag, in which social/productive life requirements differ greatly from biological needs, postponing sleep-times in favor of work or social interactions [7]. This social jet-lag is especially evident in students as their internal chronotypes are the latest and thus especially misaligned to societal restraints (Figure 1b and c).

Sleep and cognition

It is no secret that sleep is inherently related to wake activities. Concretely, sleep may exert a double pathed influence on academic performance (Figure 2): (i) sleep is essential for wake performance, namely focused attention, organization and controlled execution of cognitive operations [8]. (ii) sleep is a key player in the consolidation and refinement of previously acquired information.

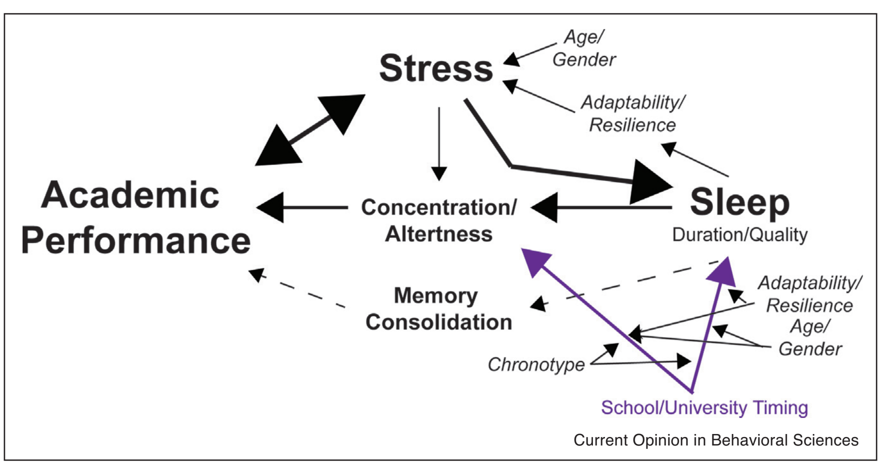
Sleep deprivation studies could show that sleep restriction has negative consequences on many cognitive tests, including motor skills, verbal learning and abstract thinking [9]. And results in children and young adolescents are comparable with those in adults [10–12]. The effects of sleep deprivation have been attributed to difficulties in maintaining focused attention, sleep intromissions, lack of impulse control (e.g. suppress an incorrect response) and impaired working memory; this is due to the sensitivity of areas in the brain, that are linked to executive function and Top-Down control such as prefrontal cortex,

Figure 1



(a) Example EEG traces and Hypnogram of a night of sleep. Sleep alternates between NonREM and REM sleep. NonREM is further subdivided into four stages with S1 and S2 known as light sleep (LS) with interspersed slow oscillations (K complexes) and sleep spindles. S3 and S4 show more delta waves and are known as slow wave sleep (SWS). REM sleep shows EEG traces similar to wake. Over a night, earlier sleep shows more SWS and later sleep shows more REM, while LS always dominates the sleep cycles. **(b)** Chronotypes will influence our natural sleep timing (purple line middle of the night) and our chronotypes are influenced by age as well as sex **(c)** Figures adapted from Ref. Roenneberg *et al.* [1] Societal constraints have a larger influence on young adults due to their late chronotypes, and especially young adults (that are late chronotypes) [41] early rising due to societal constraints leads to more sleep inertia in the morning.

Figure 2



Schematic depicting the complex interactions between sleep, stress and academic performance. Societal constraints such as School/University timings affect sleep and general concentration/alertness modulated by internal factors such as chronotype, age, gender, adaptability and resilience. Stress induced by school/university will influence sleep; sleep itself can influence academic performance directly via effects on concentration and alertness (most likely the stronger effect) or by changing basic memory consolidation processes.

to sleep deprivation [8,13]. Effects can also be associated with dysregulations of bodily functions such as temperature and appetite that depend on brain areas also controlling sleep onset. Negative effects of sleep loss can be cumulative on performance, even when the subjective feeling of impairment can cease due to habituation [14•], and may not diminish with recuperative sleep [12].

Sleep and memory consolidation

Memory, as a central function to navigate the physical and abstract world, is particularly affected by sleep and the relationship between these two processes has been long studied [15–18]. An initial hypothesis stating that sleep only played a protective role for information acquired during wakefulness against new and potentially interfering data, has been reshaped in light of growing evidence about sleep contributing actively to a key step in the process of keeping information by forming memories: memory consolidation. Through consolidation, information can be updated and changed to be incorporated into existing schemes and knowledge networks [19,20].

Research has pointed towards the importance of sleep-filled periods after acquiring new information (encoding). This has been shown for visual discrimination [21] and finger-motor tasks [22], artificial language acquisition in infants [23] as well as in a variety of tasks relying on declarative memory in both adults [24] and children [25]. Some studies have compared the effect of the time of day when learning of the experimental material occurs. Kvint *et al.* [26] have shown that the declarative component (order of a sequence of movements) is better retained when learning of the sequence occurs in the morning, compared to the afternoon training session. This is not true for the motor element (anticipatory movement to predict the sequence), which displays the same learning rate in both conditions. However, factors such as type of material and age of the person have to be taken into consideration, with younger participants showing better performances in the evening learning session [27].

Nevertheless, more critical than the time of the day when learning takes place itself, is the timing of subsequent sleep relative to encoding, which determines the effect of this process in memory consolidation [28,29]. There are relatively few studies comparing the effect of the time of the day during which sleep takes place on the memory consolidation processes. Doyon *et al.* [27] found that a 90-min nap immediately after training a sequential finger-tapping task had similar beneficial effects in performance (speed and accuracy) than a night of sleep and a delayed nap (4 hours after training); but only the night-sleep, even when delayed, prevented from losses in performance; thus a whole night of sleep had even greater positive effects than an immediate post-training nap. Results from a study in which training consisted in the observation of a finger tapping video are congruent with this beneficial effect of 'immediate sleep' (even when the time window in this second study is of less than 12 hours) [29]. Supporting evidence of the immediate versus delayed sleep effect for consolidation is provided in a declarative task, which interestingly was conducted separately with middle-school [30] and high-school students [28]. Here the researchers found that a whole-night period of sleep improves learning of German-English word-pairs when it occurs immediately after training, no matter how long the delay for testing was (12 or 24 hours). In the same vein, Potkin and Bunney [31] confirmed such findings with another group of adolescent students and extended the evidence in favor of the specific effect of immediate sleep on declarative-memory when they did not find any influence of sleep (either delayed or immediate) in a working memory task (WAIS III letter-number test).

As Diekelmann *et al.* mention [32], it is paradoxical that in experimental studies sleep takes place as soon as possible after learning the target material, while in real academic settings sleep only occurs after several hours of encoding, even surpassing the time-window for the greater effect of sleep on memory consolidation estimated between 3 and less than 12 hours.

Sleep and academic performance

Studies examining the relationship between sleep and performance on academic contexts have received some attention. Correlational studies have found association between diverse sleep features and academic performance. Gomes *et al.* [33] summarize them into four aspects: sleep quantity, quality, regularity, and synchronization of sleep time with external markers. Astill *et al.* [8] did a comprehensive meta-analysis of the published data on these features in children, and reported overall a positive significant association between sleep duration and executive functioning, school performance and multiple-domain cognitive functioning. On a similar more recent meta-analysis using only polysomnography or actigraphy measures of sleep in children ages 5–13, Short *et al.* [34] report that net sleep time had a significant effect on cognition, but when the analyzed domains of cognition were considered; only Full IQ had a positive significant correlation with sleep duration, and memory performance was the domain less explained by sleep duration.

Sadeh *et al.* [35] showed that slight manipulations of sleep onset (delay or advance by 1 hour for three days) in children ages 9–12, induced changes in sleep quality by increasing sleep efficiency in the delay group and the opposite in the advance groups; but did not alter wake-up timing. Nevertheless, children who advanced their sleep performed better on cognitive tests. This indicates that measures forcing earlier sleep onset may not produce the desired immediate effect on sleep parameters but can still be linked to an improvement in performance not explained by sleep efficiency.

Beyond the amount of time spent sleeping, the quality thereof measured by the continuity of sleep and the subjective feeling of rest are also a key-aspects. Dewald *et al.* [13] found an overall effect of sleep quality in school performance when conducting a meta-analysis collapsing 16 studies conducted in children and adolescents. They also report that sleep quality is the variable with the greatest effect on school performance, followed by sleep duration and then subjective sleepiness, but that all three have a relatively small effect.

In terms of sleep regularity, the negative effects of the characteristic irregularity that comes with development has been extensively studied in adolescents and young adults (typically college students), a group that has been described as chronically sleep-deprived [36] and suffering from social-jet-lag [37]. Phillips *et al.* [38••] calculated a numerical Sleep Regularity Index (SRI) in college students, which indicating the probability of a participant being awake or asleep at two time points separated by 24 hours. This Index was not correlated with sleep duration in the population and allowed to separate participants into 'regular' or 'irregular' sleepers. Irregular sleepers reported worse sleep quality and were more likely to have an *evening-type* chronotype, and accordingly had delayed internal and cued sleep propensity. Sleep regularity was positively correlated with academic performance (GPA) for this population.

Chronotype and academic performance

An interesting element that may exert a multi-directional influence on academic performance is chronotype. Individuals relate to their internal clock and external timings differently; such relationship can be typified into chronotypes. Roenneberg *et al.* [39] used the Munich ChronoType Questionnaire (MCTQ) to describe the prevalence of different chronotypes and their relationship with sleep aspects. In general terms, chronotype prevalence distributes normally across the population, with average mid-point of sleep between 4 and 5am, after initiating sleep around midnight on a work-free day. Sleep duration is not necessarily correlated to chronotype, but due to external constrains (work-schedule) later chronotypes get the least amount of sleep [6•]. This is in accordance with findings in academic contexts. Zerbini *et al.* [40••] indicate that late chronotypes are in disadvantage compared to early ones due, not only due to school start times (this negative relationship is mediated by absenteeism), but also to the time when academic tests take place. Interestingly the effect of chronotype depends on the type of academic subject considered, with 'scientific' subjects (physics, biology, chemistry and math) being negatively impacted for late chronotypes, while 'humanistic' subjects (languages and history) not so. This negative effect was not entirely moderated by school attendance, which is likely to affect all subjects equally. Perhaps the effect of sleep observed on academic performance is mediated by the effects of sleep on cognitive performance, according to the time of the day when different chronotypes achieve their maximum performance peak [41]. And the largest disadvantage would fall on those whose internal clock is the most misaligned to societal sleep/wake times, which are young, male students (see Figure 1b,c).

The time to go to bed and wake-up seem to play a greater role in academic performance than the chronotype itself; these elements are influenced by a multitude of factors such as daily activities determining sleep debt, meal time [41], light exposure and genetic disposition. Conscious decisions about sleep schedules are extremely important for academic performance. For instance, Genzel *et al.* [42] could show that for medical students, timing of sleep onset during the semester, and particularly on the weeks before the Final Semester Exam, correlated with academic performance, but not with sleep duration and chronotype. The authors underscore that going to bed and rising-up early may be an indicator of student's capability to adapt to university schedules. In the same note, Eliasson *et al.* [43] assert that students with the highest GPA in their community-college sample had earlier sleep times, and woke up also earlier compared to lower grade students. Lower-achievement students also tend to compute sleep needs into their class schedule, seeming unable to shift sleep-phase based on school demands.

School and university timing and sleep

Diverse literature sources have sought to disentangle the relationship between alteration of School-Start-Time (SST) and the effects it has on behavior and academic performance of the students. Kelley *et al.* [44••] report the changes in the results of the *National Examination* for students ages 13–16 from an English school, where a 10am start replaced the original 8:50 during two years, this allowed for an A-B-A comparison. Their results point out that such delay in SST was associated with a decrease in illness and absences, as well as a reduction in the gap between the school performance and the national benchmark in the exams. Those outcomes reverted as the SST went back to the original one. In the same line of natural experiments, Heissel and Norris [45•] compared the performance of students switching between schools with Central or Easter Time in the state of Florida-USA in relation to the sunrise. These researchers report that moving to a school starting one hour later than the sunrise increased the performance in the *Official State exams* in the math and reading sections. Coherently Edwards [46] reports the same increase in math and reading scores with just one more hour of sleep. In a similar direction, Lewin *et al.* [47] reviewed the differences in health and academic outcomes of Middle schools within one school district, with SSTs raging from 7:20 to 8:10am. They found that both, grades, as well as self-reports of effort are linked to later SST and that the relationship may be mediated by the effort exerted in completing the homework by students with longer sleep durations.

Among the reviews on the topic, the common conclusion based on the analysis of the articles is that later SST increases sleep durations by extending sleep in the morning and not by advancing bed time [48,49]. Later SST correlates with less involvement in risky behaviors (i.e. smoking and drinking), less car accidents and less frequent reports of depressive symptoms [50•]. Academic performance is often reported as affected positively by later SST due to the impact on sleepiness and tardiness/absenteeism [49,51•]. The direct association of SST change and grades is often reported as more difficult to establish [36,51•].

Individuals have different wake and sleep timings, this could be explained in evolutionary terms by the need to have vigilant members of groups who protect the rest [52]. Despite the evidence for these individual differences and their consequences for peak performance, organizational considerations impose uniform starting times for educational institutions, an approach that according to Evans *et al.* [53••] is not optimal for all individuals. This implies that some students will be sacrificed and their chronotype will handicap their academic performance. The same authors showed, using a subjective preference model and a neuroscience-based one, that students in a college sampled in the USA are functioning outside their preferred peak performance period and there are clearly two chronotypes as per the bimodal trend in their results. These findings imply that the optimal activity schedule would vary according to the preferences of individuals due to their chronotype and therefore consensual start and end times for school will be difficult to attain, so the goal will be to achieve a period where the gap between chronotypes is minimal.

Conclusion

School and university are per definition domains where memory about facts and rules are cultivated, therefore, the importance of sleep on academic performance is centrally mediated by the possibility to encode, consolidate and recall the information acquired into the classroom and be used in different contexts and settings. In this regard, sleep as preferred space for memory consolidation has a central role in academic performance.

In order to disentangle the complex relationship between sleep – and its timings – to academic performance is necessary to consider a series of aspects (Figure 2) which requires further research both within the laboratory and more natural school settings. For instance, an important factor that has been traditionally overlooked in the studies linking sleep and academic performance is academic stress. It is well known that stress alters among other bodily functions sleep regulation, duration and quality [54]. As illustration, sleep duration during examination periods is reported to be reduced at least by 20 min [55]. Stress alters sleep quality, especially in highly competitive areas such as medical school [56]. The complex interaction of stress, sleep and academic performance also highlights the importance of resilience to externally imposed stressors and factors as well as flexibility. Flexibility is a key aspect for the entrainment of biological (circadian) rhythms with external activities schedule. Such a flexibility will facilitate that individuals adjust their schedules and habits, and therefore had more regulated sleep-wake cycles [6•]. On the same note, flexibility could be an approach for institutions to allow for more organic cycles in their students, including naps [57] and alternative test-times.

Regulatory dispositions about timing in individual activities tend to be based on 'normality', such concept rises from the idea of *a* norm and deviance; however, still there is lacking information on the normality of many circadian-regulated cognitive processes (i.e. memory, attention, executive functions). The idea of a perfect student who goes to bed early and wakes up fresh and ready to learn has molded school timings. Perhaps now is the optimal time for data to be produced regarding the timings of central cognitive processes and on compensatory mechanisms (over-training, spaced learning sessions, distributed sleep opportunities) available to counteract the time-of-day-learning by chronotype effect and to use such information to fuel the discussion on the regulations of student's activities, and more importantly the setting of school and university start times [43].

Conflict of interest statement

Nothing declared.

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- • of special interest
- •• of outstanding interest

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52. Samson DR, Crittenden AN, Mabulla IA, Mabulla AA, Nunn CL: **Chronotype variation drives night-time sentinel-like behaviour in hunter-gatherers**. *Proc R Soc B Biol Sci* 2017, **284** 20170967.

53. Evans MDR, Kelley P, Kelley J: **Identifying the best times for cognitive functioning using new methods: matching university times to undergraduate chronotypes**. *Front Hum Neurosci* 2017, **11**:188.
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This article seeks to shed light into the discussion of optimal start times at the university level, based on an empiral model created from results of a student survey and a neuroscience model from literature review. Results indicate that actual sleep habits differ form the biological optimal model identified from the literature. This is linked to the mismatch between university schedules and students clocks (later chonrotypes). Authors suggest an unique start time will inherently compromise the performance of some students, but a more reasonable 10–11am start may be more suitable.

54. Sanford LD, Suchecki D, Meerlo P: **Stress, arousal, and sleep**. *Curr Top Behav Neurosci* 2015, **25**:379-410.

55. Heissel JA, Levy DJ, Adam EK: **Stress, sleep, and performance on standardized tests: understudied pathways to the achievement gap**. *AERA Open* 2017, **3** 233285841771348.

56. Ahrberg K, Dresler M, Niedermaier S, Steiger A, Genzel L: **The interaction between sleep quality and academic performance**. *J Psychiatr Res* 2012, **46**:1618-1622.

57. Lemos N, Weissheimer J, Ribeiro S: **Naps in school can enhance the duration of declarative memories learned by adolescents**. *Front Syst Neurosci* 2014, **8**:103.