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Conflicted clocks: social jetlag, entrainment and the role of chronotype

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Summary

The rotation of the earth on its axis and around the sun determines regular changes in the environment, namely the alternation of day and night and of seasons. Nearly all organisms on earth have developed an internal time keeping mechanism (circadian clock) to synchronize (entrain) to the external light-dark cycle. Exposure to light is important in determining the phase of entrainment, but other individual factors such as sex, age, and genetic background play a role as well. As a result, humans can entrain with very different phases to the external light-dark cycle, giving rise to a wide distribution of chronotypes that ranges from early (larks) to late (owls) types.

Chronotype can be easily assessed with questionnaires (e.g Munich ChronoType Questionnaire; MCTQ) as the midpoint of sleep on work-free days (MSF), corrected for sleep debt accumulated on workdays (MSF_{sc}). Modern society often ignores this rich variety in sleep timing by imposing uniform (usually early) school and working starting times. As a result, the circadian clock of especially late chronotypes is often in conflict with the social clock, giving rise to a phenomenon called social jetlag (absolute difference between the midpoint of sleep on work-free days and on workdays).

The main objectives of this thesis were to describe the consequences that arise from the conflict between biological (circadian) and social clocks (part 1; chapters 2-5), to explore possible solutions to reduce social jetlag (part 2; chapter 6), and to better understand entrainment in real life conditions (part 3; chapters 7 and 8).

In **chapter 2** and **3** we investigated the role of chronotype and school attendance in relation to school performance in high-school students. Previous literature had shown that late chronotypes on average obtain worse school grades than early chronotypes. Here we showed that the chronotype-effect on grades depends on time of day (the effect is stronger in the morning) and on school subject (the effect is stronger for scientific subjects). In addition, we found that late chronotypes were more likely to be absent from class, and that absenteeism, in turn, was negatively associated with school performance. These findings suggest new hypotheses about how chronotype impacts school performance. Since late chronotypes sleep shorter on school days, insufficient sleep has always been considered a possible factor associated with lower school performance. However, our analysis showed that chronotype was a stronger predictor of school grades than sleep duration. The dependency on time of day of the chronotype-effect suggests that students with a late chronotype achieve lower grades particularly when tested at a non-optimal time of day (often late chronotypes are tested during their biological night). The dependency of the chronotype-effect on school subjects suggests that chronotype might influence specific cognitive abilities (e.g. fluid intelligence) that are important for scientific subjects.

In **chapter 4** we aimed to expand our previous results about the interaction effect between chronotype and time of day on grades. We assessed chronotype and collected grades in university students because they are examined early in the morning as well

as late in the evening. Unfortunately, the distribution of grades over the course of the day was not uniform, with too few grades collected in the evening, which limited the interpretation of our results. Interestingly, also in this study, chronotype was associated with attendance (late chronotypes attended fewer lectures). Attendance and study effort were stronger predictors of grades than chronotype, suggesting that the chronotype-effect on grades is evident particularly in contexts where students are expected to attend classes early in the morning (most universities have more flexible schedules than schools).

In **chapter 5** we reviewed the literature about the relationship between chronotype and school performance, suggesting possible mechanisms behind a lower school performance in late chronotypes. Chronotype is likely to have both a direct and an indirect effect, with the latter effect being mediated by other factors important for school performance such as conscientiousness and motivation. The chapter ends with some suggestions regarding possible changes in school policies (e.g. tests scheduled later in the day) that would allow for testing all students on an even ground without any discrimination against late chronotypes.

In **chapter 6**, two light protocols were assessed for how well they could decrease social jetlag. The first study involved a decrease in evening light exposure by wearing blue-light-blocking glasses, and the second study involved an increase in morning light exposure by sleeping with open curtains. We found that filtering out blue light during the hours before going to sleep was associated with an advance in both sleep timing (on workdays) and in dim-light melatonin onset (DLMO). Sleeping with open curtains did not yield the same expected results at the group level, but the change in DLMO during the intervention week was associated with the increase of light in the bedrooms (participants who experienced a greater increase of light in their bedrooms showed a greater advance in their DLMO). In both studies the effects were stronger during the first intervention week. Further studies are needed to determine the long-term effects of such interventions.

In both studies, we were not able to decrease the social jetlag of our participants. However, social jetlag at baseline was quite low (on average 1.5 hours), possibly leaving not enough room for improvement. Future studies should test the effectiveness of these or similar light interventions to decrease social jetlag in extremely late chronotypes who suffer from more than 2 hours of social jetlag.

In **chapters 7 and 8**, we aimed to better understand entrainment in real life conditions by assessing the influence of season (photoperiod) and weekly structure (work/school days vs. work-free days) on behavior (school attendance and performance), sleep, activity, and phase of entrainment (DLMO). We found that school attendance varied according to season with a peak in absenteeism in winter. Photoperiod was the strongest predictor of this seasonal variation in school attendance. Sleep, activity, and DLMO were mainly influenced by the weekly structure (not by season). All

parameters were later on work-free days. While this is known for sleep (social jetlag), there is less evidence that DLMO also varies between workdays and work-free days. We found a delay in DLMO over the weekend and this was more pronounced in later chronotypes.

In conclusion, I have shown in this thesis how the circadian clock and its entrainment are challenged by modern society, leading to important handicaps in late chronotypes in terms of, for example, school performance. With our studies, we have increased our understanding of how chronotype impacts school performance and attendance by showing that the chronotype-effect on grades depends on time of day and school subject, and by showing that late chronotypes are more likely to be absent from class, which, in turn, lowers their school performance.

In this thesis, I have also reported the results of two studies that aimed to decrease the mismatch between the circadian and social clocks (social jetlag). Although social jetlag was not reduced, these findings show that simple 'in-home' light interventions are potentially effective in modifying phase of entrainment and sleep timing, confirming the results of previous laboratory studies about the effects of light on the circadian clock.

Finally I have shown how both season and weekly structure can influence entrainment in terms of behavior (school attendance and performance), sleep, activity and DLMO.

The findings of this thesis have important applications for society. Suggestions to improve school policies and practical solutions to delayed sleep have been developed. Most importantly, this work has generated several interesting hypotheses to be tested in future studies.