**Title: Effects of a 20 minutes delay in school start time on bed and wake up times, daytime tiredness, behavioral persistence, and positive attitude towards life in adolescents**

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*Objectives*: Preliminary evidence suggests that delaying school start times is an effective tool for improving adolescent sleep duration. Our study assessed whether a policy driven 20-minute delay in school start times led to an increase in adolescents' weekday bed and wake up times.

*Method*: Data collected via school satisfaction surveys concerned 663 students (45.2% females, Mean age: 14.91 years, SD = .58 years) in three lower-track secondary schools in Switzerland. Of all the students, 249 experienced a policy-driven 20-minutes school start time change (SSTc), from 7.40 am to 8.00 am between the 8$^{th}$ and 9$^{th}$ grade, while 414 students did not (Comparison Group/CG). Students filled out the survey twice, at the end of their 8$^{th}$ and 9$^{th}$ grades, respectively, and reported their weekday bed and wake up times, daytime tiredness, behavioural persistence, and positive attitude towards life.

*Results*: Generalized estimating equations models of bed and wake up times showed that there was a significant delay in both the bed and wake up times of the students in the SSTc group. Multilevel analyses revealed that students in the SSTc group did not significantly differ from CG students in daytime tiredness, behavioural persistence, and positive attitude towards life.

*Conclusions*: Findings suggest that not only wake up times but also bed times may shift later when school start times are delayed. The 20 minutes delay in school start times may have been too slight to have an impact on daytime tiredness, behavioral persistence and positive attitude towards life.

Keywords: Delaying school start time; adolescent sleep; mental wellbeing

Abbreviations: SSTc - School Start Time change group; CG – Comparison Group

**1. Introduction**

Chronic sleep reduction can have detrimental effects on the lives of adolescents, with evidence linking it to decreased mental and physical alertness, increased feelings of anxiety, depression and hopelessness, poor academic performance, and obesity, among others (Dewald, Meijer, Oort, Kerkhof, & Bögels, 2010; Minges & Redeker, 2016; Paruthi et al., 2016; Perkinson-Gloor, Lemola, & Grob, 2013; Wahlstrom, Berger, & Widome, 2017). These findings become paramount considering that adolescents experience difficulty in maintaining schedules meeting their recommended 8 to 10 hours of sleep per night (Hirshkowitz et al., 2015; Morgenthaler et al., 2016; Short, Weber, Reynolds, Coussens, & Carskadon, 2018). Apart from psychosocial and behavioural factors such as increased academic stress and evening leisure-time use of electronic devices (Lemola, Perkinson-Gloor, Brand, Dewald-Kaufmann, & Grob, 2015), there is evidence that biological changes associated with puberty contribute to a shift in adolescents' circadian clock, characterized by a delay in dim light melatonin onset and offset (Crowley, Acebo, & Carskadon, 2007; Roenneberg et al., 2004). This delay results in a preference for later sleep and awakening times, earning adolescents' the tag of 'evening owls' (Gradisar, Gardner, & Dohnt, 2011; Hershner & Chervin, 2014). The circadian phase delay becomes more pronounced for older adolescents, peaking at about 20 years of age (Roenneberg et al. 2004). The mismatch between adolescents' sleeping habits and for instance, early weekday school start times results in a large proportion of adolescents experiencing chronic sleep deprivation (Bowers & Moyer, 2017; Hysing et al., 2015; Watson et al., 2017).

There is preliminary evidence that adolescents' chronic sleep reduction could be improved by delaying school start times. Delaying school start times is associated with longer sleep duration in the morning while evening bedtimes often remain unchanged resulting in increased total sleep time on weekdays, and leading to less daytime sleepiness, decreased tardiness, and less depressive feelings (Boergers et al., 2014; Minges & Redeker, 2016; Owens, 2014; Perkinson-Gloor et al., 2013; Wahlstrom 2002; Wolfson, Spaulding, Dandrow, & Baroni, 2007). However, a recent Cochrane Systematic Review and meta-analysis (Marx et al., 2017) summarizing all the relevant available evidence concluded that despite promising findings, there is lack of robust and conclusive evidence to support policy changes to delay school start times to improve sleep in adolescence. A major hurdle identified in the review is that all the summarized studies either lacked a controlled design or there was no random assignment of schools or school classes to the intervention or control groups.

The lack of robust evidence is mainly explained by challenges associated with implementing randomised controlled experimental studies within school systems where several stakeholders including students, parents, teachers, and employees in peripheral services (e.g. transportation service employees) are affected (Lee, Nolan, Lockley, & Pattison, 2017; Marx et al., 2017; Morgenthaler et al., 2016; Wahlstrom et al., 2017). Even when legal obstacles are overcome, the implementation of delayed start time interventions often fails due to parents' and teachers' opposition to longer school days (Marx et al., 2017) or due to concerns of the broader society outside school, such as sports and arts classes facilitators (Wahlstrom, 2002). Recently, the Oxford Teensleep study illustrated the challenges related to recruiting schools into a randomised controlled study involving school start time change. The project that attempted randomising 100 schools in the United Kingdom either to a delayed start time at 10 a.m. condition or start time as usual at 9 a.m. condition was able to recruit only two schools in total. This was despite extensive advertising efforts, positive media coverage, availability of financial incentives of £1,000 per participating school, direct contact with 400 state secondary schools in England and Wales and e-mail contact with in total 3,985 schools (Illingworth et al., in press).

1.1 The current study

In a study exploring the cross-sectional differences between one school that started at 8.00 am and five schools that started at 7.40 am, during the years 2010 and 2011, in Basel, Switzerland, Perkinson-Gloor et. al. (2013) found that students in the school with later start times reported longer sleep duration by 16 minutes and less daytime tiredness, which were driven by later wake times and nearly unchanged bedtimes. These findings provided preliminary evidence that a delay in school start times by merely 20 minutes may already be an effective measure for improving chronic sleep deprivation and daytime tiredness among adolescents. However, due to the cross-sectional design of the study, these findings have to be considered as only tentative. The current study attempts to overcome this limitation by evaluating a policy decision taken in 2013 to delay school start times by 20 minutes (from 7.40 am to 8.00 am) in state schools in the city of Basel. Data taken twice a year apart (i.e. before and after school start time change) is available for one school that delayed school start times with effect on 1 August 2014 and from two schools that delayed school start times with effect on 1 August 2015. Data from previous year-cohorts of the same schools were used as the comparison group.

Based on existing evidence (Boergers et al., 2014; Minges & Redeker, 2016; Owens, 2014; Perkinson-Gloor et al., 2013; Wahlstrom 2002; Wolfson, Spaulding, Dandrow, & Baroni, 2007) and in line with the notion that during adolescence, circadian preference shifts later (Crowley, Acebo, & Carskadon, 2007; Gradisar, Gardner, & Dohnt, 2011; Hershner & Chervin, 2014; Roenneberg et al., 2004), as our primary hypothesis, we expect that weekday wake up times were delayed among students in the school start time change condition relative to the comparison condition while bedtimes remained the same. As secondary hypotheses, we expect an increase in the length of the time window when sleep can occur on weekdays (i.e.

the estimated time spent in bed), improvements in psychosocial adjustment including daytime tiredness, behavioural persistence, and positive attitude towards life in association with the delayed school start time relative to the comparison group.

## 2. Materials & Methods

### 2.1 Data source

Data are from 8$^{th}$-grade and 9$^{th}$-grade classes from three lower-track secondary schools in Basel, the so-called "*Weiterbildungsschulen*". At the time of data collection, in the school system of the City of Basel, *Weiterbildungsschulen* included around half of all 8$^{th}$ and 9$^{th}$ grade students of the City's population while the other half of the population attended the Gymnasium (i.e. the higher track secondary school). Students entered the Weiterbildungsschulen, when they came into the 8$^{th}$-grade and left after they completed the 9$^{th}$-grade. Data were collected at the end of every school year, in June, as part of the student school satisfaction survey that aims to provide teachers and schools managers with feedback. Students filled in the feedback questionnaire on-line, during school lessons. The questionnaire also included questions on bedtimes and wake times, daytime tiredness, behavioural persistence, and positive attitude towards life. The researchers were allowed access to anonymised survey data to analyse and report yearly student satisfaction rates and sleep behaviour.

The design of the study is shown in Figure 1. Consecutive student satisfaction survey data from three schools are available for school years: 2012/13; 2013/14; 2014/15; and 2015/16. Only data on students who completed the survey twice (i.e. when they were 8$^{th}$-graders and 9$^{th}$-graders) were analysed. Hence, the analyses involve data from three consecutive cohorts; 1$^{st}$ cohort: Aug 2012-June 2014; 2$^{nd}$ cohort: Aug 2013-June 2015; 3$^{rd}$ cohort: Aug 2014-June 2016. Across all three schools in Cohort 1, students started lessons at

7.40 am at both time points (n=275; *k*=23 school classes). In Cohort 2, students in two schools started at 7.40 am at both time points (n=139; *k*=14 school classes), while students in the third school started at 7.40 am at the first time point, but at 8.00 am at the second time point (n=61; *k*=4 school classes). Finally, in Cohort 3, students in the first two schools started their program at 7.40 am at the first time point, but at 8.00 am at the second time point (n=188; *k*=15 school classes). Thus, a total of 249 students (clustered within 19 school classes) experienced a change in school start time between their 8$^{th}$ grade and 9$^{th}$ grade and are treated as the School Start Time Change Group (SSTc), whereas 414 students (clustered within 37 school classes) did not experience any change in school start time and are treated as the Comparison Group (CG). For students in the SSTc group, the number of school lessons or the end of school in the evening did not shift to a later time, but they had shorter lunch breaks. Across the whole study period, the latest school end time was consistently at 5pm. For all students, the school week included 34 school lessons lasting 45 minutes each. The study involving an analysis of the student feedback survey data was approved by the Humanities and Social Sciences Research Ethics Sub-Committee of the University of Warwick (159/17-18).

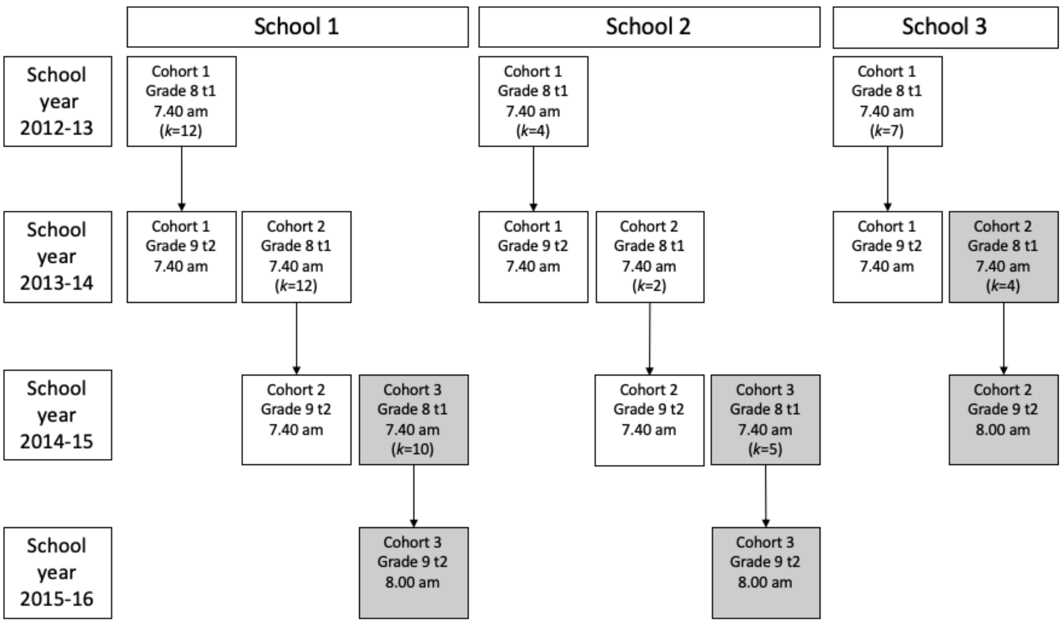

Figure 1. Study design. The School start time change group experiencing school start time change between the 8th and 9th grade is denoted with grey shade; *k* denotes the number of school classes per cohort and school. In School 1 and School 2 the school start time was changed at the beginning of school year 2015-16; in School 3 the school start time was changed at the beginning of school year 2014-15.

## 2.2 Sample characteristics

Student characteristics are shown in Table 1. In total, there were 300 females (45.2%), the average age of the sample was 14.91 years (*SD*= .58 years) at the end of the 8th grade (t1). Around two thirds of the sample reported that German was not their first language (67.6%), with Albanian (10.9%), Turkish (9.4%), Serbian/Croatian/Bosnian (8.3%), Portuguese (5.7%), Italian (5.4%), and Kurdish (5.0%) being the most frequent first languages after German. This indicates the high number of students with non-German migration family background in lower track secondary schools in Switzerland, which is often associated with lower socioeconomic background compared to the average Swiss family or migrant families from Germany (Swiss Federal Office of Statistics, 2011). It is also common for adolescents of migrant origin to attend lower track secondary schools. However, students in these schools are required to be fluent in German, and therefore participants were able to successfully complete the questionnaire.

## 2.3 Measures

Bed times, wake up times, and estimated time spent in bed on weekdays. For school day bedtimes (Monday-Thursday), students could select an option from the following categories: '*before 9:30 pm', '9:30–9:59 pm', '10–10:29 pm', '10:30–10:59 pm', '11–11:29 pm'* and '*after 11:30 pm'*. Similarly, the categories for wake time on school days (Monday-Friday) were '*before 6 am', '6–6:29 am', '6:30–6:59am'* and '*7 am or later'*. Further, for secondary analyses the estimated time spent in bed on weekdays was inferred based on the answers to these two items, i.e., the time when sleep could occur based on estimated bedtimes and wake up times. In detail, the bedtime category '*before 9:30 pm'* was represented with an estimated bedtime of 9:15 pm, the category *'9:30–9:59 pm'* with an estimated bedtime of 9:45 pm, the category *'10–10:29 pm'* with an estimated bedtime of 10:15 pm, the category *'10:30–10:59 pm'* with an estimated bedtime of 10:45 pm, the category *'11–11:29 pm'* with an estimated bedtime of 11:15 pm, and the final category '*after 11:30 pm'* with an estimated bedtime of 11:45 pm. Similarly, the wake up time category on school days of '*before 6 am'* was represented with an estimated wake up time of 5:45 am, the category of *'6–6:29 am'* with an estimated wake up time of 6:15 am, the category of' *'6:30–6:59am'* with an estimated wake up time of 6:45 am, and finally, the wake up time category of '*7 am or later'* with an estimated wake up time of 7:15 am. The estimated time spent in bed on weekdays was inferred by taking the difference between the estimated wake up time and the estimated bedtime. For example, for a student who reported bedtime as *10–10:29 pm* and wake time as *6–6:29 am,* the estimated time spent in bed on weekdays was 8 hours, resulting from the difference between 10:15 pm and 6:15 am.

Daytime tiredness. Daytime tiredness was assessed with two items ('*At school I am often so tired that I almost fall asleep' and 'Recently, I have often been tired and sleepy all day')* with a 6-point Likert-type scale (*1=don't agree at all* and *6=completely agree).* Internal consistency was high (school year 1: $\alpha = .81$; school year 2: $\alpha = .81$). Stability between school year 1 and school year 2 was $r$ (663) = .43, $p < .001$. Higher mean scores reflected greater daytime tiredness.

Behavioral persistence. Behavioral persistence was measured with four items from the Description of School Environment Scale focusing on the perceived achievement pressure (e.g., *I often quit when I am facing the first difficulty*) (Fend & Prester, 1986) with a 6-point Likert-type scale (*1=don't agree at all* and *6=completely agree*) (school year 1: $\alpha = .74$;

school year 2: α=.72). Stability between school years 1 and 2 was $r$ (663) = .41, $p < .001$. The scale was recoded so that higher mean scores indicate higher behavioural persistence.

Positive attitude toward life. Positive attitude toward life was measured with two items from the Berne Questionnaire on Adolescent Subjective Well-being (e.g. '*I am satisfied with how my life plans are getting fulfilled*' and *'My future looks good'*) (Grob et al., 1996) with answers ranging on a 6-point Likert-type scale (*1=don't agree at all* and *6=completely agree*) (school year 1: α=.68; school year 1: α=.78). Stability between school years 1 and 2 was $r$ (663) = .38, $p < .001$. Higher mean scores indicated increased positive attitude towards life.

2.4 Statistical analysis

Preliminary analyses involved a baseline comparison between SSTc group and CG for outcome variables (Mann-Whitney U-tests for ordinal outcome variables and independent samples t-tests for continuous outcome variables) and for students' age (independent samples t-test), gender, and mother tongue (chi-square tests). Furthermore, associations of outcome variables at baseline with age (Spearman's rank correlations for ordinal outcome variables and Pearson's correlations for continuous outcome variables), gender, and mother tongue (Mann-Whitney U-tests for ordinal outcome variables and independent samples t-tests for continuous outcome variables) were tested.

Primary analyses involved generalised estimating equations (GEE) using ordinal logistic models for comparisons of changes in wake up times and bedtimes between the two groups controlling for gender, age and mother tongue.

Further, as secondary analyses, effects of SSTc on the estimated time spent in bed, daytime tiredness, behavioural persistence, and positive attitude towards life were analysed. These analyses involved multilevel models to account for the nested nature of the data, with students clustered within school classes in either the SSTc group or CG. The multilevel models assessed the effect of the change in school start time on the outcome variables by treating group and time as independent variables, and participant and school class as random factors, controlling again for gender, age and mother tongue. An interaction term of Group*Time was also included in each model. A separate model was computed for each outcome variable. The preliminary and primary analyses were conducted using SPSS® version 24 (IBM Corporation, Armonk NY, USA). Multilevel analysis was implemented using the xtset and xtmixed STATA (version 15) statistical software.

## 3. Results

### 3.1 Preliminary analyses

Baseline differences between the CG and SSTc students are shown in Table 1. Baseline group comparisons revealed older age ($t(661) = 3.21$, $p < .001$, $d = 0.26$), earlier weekday wake time (Mann-Whitney *U-test*, $Z = –2.55$, $P = 0.011$), and a shorter estimated time spent in bed on weekdays ($t(661) = -2.14$, $p = .03$, $d = 0.18$) in CG versus SSTc students. No other differences between the SSTc and CG students were found at baseline. Further, associations of age, gender, and mother tongue with study variables at baseline were tested. Students' age at baseline was significantly correlated with later weekday bedtimes ($\rho = 0.13$, $p=.001$), the estimated time spent in bed on weekdays ($r = –0.15$, $p<.001$), and behavioural persistence ($r = 0.11$, $p < .005$), but not with weekday wake times, daytime tiredness, and positive attitude towards life. Compared to boys, girls had earlier wake times (Mann-Whitney *U-test*, $Z = –6.30$, $p < 0.001$) while there were no significant gender differences regarding bedtimes, estimated time spent in bed, daytime tiredness, behavioural persistence, and positive attitude towards life. No significant associations of German as mother tongue was observed with bedtimes and wake times, estimated time spent in bed, behavioural persistence, daytime tiredness, and positive attitude towards life.

Table 1.
Descriptive statistics separately for school start time change group and comparison group at both time points.

| | School Start Time Change Group (*n* = 249) | | | | Comparison Group (*n* = 414) | | | |
|---|---|---|---|---|---|---|---|---|
| | *t1* | | *t2* | | *t1* | | *t2* | |
| | *Mean N* | *SD %* | *Mean N* | *SD %* | *Mean N* | *SD %* | *Mean N* | *SD %* |
| Age (years) (*Mean SD*) | 14.82 | 0.54 | | | 14.97 | 0.60 | | |
| Females (*N %*) | 104 | 41.8 | | | 196 | 47.3 | | |
| First language (no. with German as first language) (*N %*) | 74 | 29.7 | | | 141 | 34.1 | | |
| Bedtime weekdays (*N %*) | | | | | | | | |
| Before 9.30 pm | 22 | 8.8 | 10 | 4.0 | 40 | 9.7 | 26 | 6.3 |
| 9.30-9.59 pm | 62 | 24.9 | 36 | 14.5 | 97 | 23.4 | 59 | 14.3 |
| 10.00-10.29 pm | 79 | 31.7 | 66 | 26.5 | 134 | 32.4 | 124 | 30.0 |
| 10.30-10.59 pm | 49 | 19.7 | 49 | 19.7 | 69 | 16.7 | 91 | 22.0 |
| 11.00-11.29 pm | 23 | 9.2 | 41 | 16.5 | 38 | 9.2 | 64 | 15.5 |
| After 11.30 pm | 14 | 5.6 | 47 | 18.9 | 36 | 8.7 | 50 | 12.1 |
| Estimated weekday bedtime[1] (*Mean SD*) | 10.18 pm | 43min | 10.43 pm | 49min | 10.20 pm | 47min | 10.35 pm | 47min |
| Wake up time weekdays (*N %*) | | | | | | | | |
| Before 6.00 am | 36 | 14.5 | 23 | 9.2 | 84 | 20.3 | 48 | 11.6 |
| 6.00-6.29 am | 86 | 34.5 | 55 | 22.1 | 156 | 37.7 | 139 | 33.6 |
| 6.30-6.59 am | 102 | 41.0 | 94 | 37.8 | 145 | 35.0 | 172 | 41.5 |
| 7.00 am or later | 25 | 10.0 | 77 | 30.9 | 29 | 7.0 | 55 | 13.3 |
| Estimated weekday wake up time[2] (*Mean SD*) | 6.28 am | 32min | 6.46 am | 37min | 6.22 am | 33min | 6.32 am | 32min |
| Estimated time spent in bed on weekdays (h)[3] (*Mean SD*) | 8h 10min | 52min | 8h 2min | 54min | 8h 1min | 51min | 7h 58min | 49min |
| Daytime tiredness (*Mean SD*) | 3.30 | 1.42 | 3.56 | 1.51 | 3.20 | 1.47 | 3.32 | 1.54 |
| Behavioral persistence (*Mean SD*) | 3.28 | 1.04 | 3.19 | 1.09 | 3.40 | 1.01 | 3.20 | 1.00 |
| Positive attitude toward life (*Mean SD*) | 4.81 | .89 | 4.53 | 1.24 | 4.77 | .86 | 4.66 | 1.11 |

*Note*.
[1] To derive estimated bedtimes the bedtime category '*before 9:30 pm*' was indicated with an estimated bedtime of 9:15 pm, the category *'9:30–9:59 pm'* with an estimated bedtime of 9:45 pm, the category *'10–10:29 pm'* with an estimated bedtime of 10:15 pm, the category *'10:30–10:59 pm'* with an estimated bedtime of 10:45 pm, the category *'11–11:29 pm'* with an estimated bedtime of 11:15 pm, and the final category '*after 11:30 pm*' with an estimated bedtime of 11:45 pm.
[2] To derive the estimated wake up time, the category on school days of '*before 6 am*' was indicated with an estimated wake up time of 5:45 am, the category of *'6–6:29 am'* with an estimated wake up time of 6:15 am, the category of *'6:30–6:59am'* with an estimated wake up time of 6:45 am, and finally, the wake up time category of '*7 am or later*' with an estimated wake up time of 7:15 am.
[3] The estimated time spent in bed on weekdays was inferred by taking the difference between the estimated wake up time and the estimated bedtime.

## 3.2 Effects of school start time change

Generalised estimating equations with ordinal probit distribution were fitted showing a significant delay in both bedtimes (*B*= 0.34, *C.I.*= 0.08, 0.61; Wald Chi-Square (1) = 6.389, $p$ <.011) and wake up times (*B*=0.43, *C.I.* = 0.12, 0.74; Wald Chi-Square (1) = 7.420, $p$ <.006) among students in the SSTc group.

Tests of secondary hypotheses applying multilevel models showed no significant effect of delayed school start time on the estimated time spent in bed on weekdays (β = -0.07, *SE* = 0.07, $p$ = .308) indicating that the delay of weekday bedtimes among students in the SSTc group between 8$^{th}$ and 9$^{th}$ grade compared to the CG students may have cancelled out their delay in wake times (Table 2). On average, students with a delay in school start time had later estimated bedtimes by 25 minutes and later estimated wake up times by 18 minutes, in 9$^{th}$ grade compared to when they were in the 8$^{th}$ grade. Students with continuous early start times in both years had on average 15 minutes later estimated bedtimes and 10 minutes later estimated wake up times in 9$^{th}$ grade compared to the 8$^{th}$ grade (see Table 1). Further, multilevel models showed no significant effects of SSTc on daytime tiredness (β = 0.14, *SE* = 0.13, $p$ = .266), behavioural persistence (β = 0.12, *SE* = 0.09, $p$ = .182), and positive attitude towards life (β = -0.17, *SE* = 0.09, $p$ = .070).

Table 2.
Secondary analyses: Multilevel analyses with outcome variables as a function of group, time, and Group × Time controlling age, gender, and mother tongue.

| | | Group | | | Time | | | Group × Time | | | ICC[2] (SE[3]) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *n*[1] | β | *CI* | *p* | β | *CI* | *p* | β | *CI* | *p* | |
| Estimated time spent in bed on weekdays | 1326 | 0.12 | -0.02, 0.26 | .095 | -.06 | -0.14, 0.02 | .162 | -0.07 | -0.21, 0.07 | .308 | 0.47 (.03) |
| Behavioural persistence | 1326 | -0.13 | -0.33, 0.09 | .242 | -0.20 | -0.31, -0.09 | .000 | 0.12 | -0.34, 0.29 | .182 | 0.41 (.03) |
| Positive attitude towards life | 1326 | 0.05 | -0.16, 0.27 | .634 | -0.11 | -0.22, -0.00 | .046 | -0.17 | -0.35, 0.01 | .070 | 0.37 (.03) |
| Daytime tiredness | 1326 | 0.11 | -0.16, 0.38 | .416 | 0.12 | -0.04, 0.27 | .137 | 0.14 | -0.11, 0.39 | .266 | 0.43 (.03) |

*Note.* Models were built adjusting for sex, age and mother tongue. Sex, age, mother tongue and constant values are not displayed in the table.
[1] number of data points in the model; there were 2 data points per participant (baseline and follow-up).
[2]ICC: Intracluster correlation coefficient
[3]SE: Standard Errors

## 4. Discussion

Our study evaluated the effect of delaying school start times from 7.40 am to 8 am on adolescents' bed and wake up times on weekdays, across three schools compared to a comparison group drawn from previous year-group cohorts of the same schools with continued school start times at 7.40 am. Results showed that the 20 minutes delay intervention associated with a significant delay in both bed and wake up times, while no effects were observed on the estimated time spent in bed, daytime tiredness, behavioural persistence or positive attitude towards life.

In contrast to an earlier cross-sectional study (Perkinson-Gloor et al., 2013) that showed that 20 minutes of delay in school start time was associated with longer weekday sleep duration, less daytime tiredness, later wake up times but unchanged bedtimes, our current findings suggest that although a delay in school start times allowed students to get up later, that shift might be cancelled out by concurrent delayed bedtimes. Moreover, no differences were observed regarding the reported daytime tiredness. This suggests that a SSTc of 20 minutes might be effective in delaying overall sleeping patterns among students, but it may be too short a delay to result in changes in sleep related secondary outcomes and particularly daytime tiredness, behavioural persistence and positive attitude towards life. However, a key difference in the methods and subsequent analyses between the previous and current study could explain why results differ. Due to the cross-sectional comparison between early (data of five schools) and delayed (data of one school) start times, within-person changes could not be evaluated in Perkinson-Gloor et al.'s (2013) study. In the same vein, data of only three schools were included in the current study due to unavailability of follow-up data i.e. before and after the implementation of the delayed start times.

Previous studies showing a positive impact of delaying school start times on sleep duration and mental wellbeing indicators investigated longer delays of often one hour or more (Minges & Redeker, 2016; Wolfson et al., 2007), except for studies, for instance, by Owen et al. (2010) and Boergers, Gable and Owens (2014). Owen et al. (2010) showed that a modest delay of 30 minutes in school start time (from 8 am to 8.30 am) resulted in increased sleep duration, and decreased daytime sleepiness, depressed mood and fatigue. Moreover, Boergers et al. (2014) observed similar encouraging changes with a respective 25 minutes delay. Putting the evidence together, it is possible that a change of 25 to 30 minutes in school start time is the lowest threshold for a beneficial impact on adolescents' sleep and wellbeing. However, it is important to consider that while the SSTc students in the current study experienced the same school end times in the evening (i.e. 5 pm) and number of classes as the CG students, they also experienced shorter lunch breaks. It is therefore possible the shorter break may have imposed a negative impact on the variables examined in this study, for instance, daytime tiredness, and cancelled out any potential effect of the delay in school start time.

Second, it is possible that the increase in social media use in recent years has diluted the potential benefits of delayed school start times. Evidence suggests that increased electronic and social media use is associated with insufficient sleep, poor sleep quality, and poorer mental wellbeing in adolescents (Cain & Gradisar, 2010; Fossum, Nordnes, Storemark, Bjorvatn, & Pallesen, 2014; Hysing et al., 2015; Lemola et al., 2015; Owens, 2014; Twenge et al., 2017). The implementation of the delay in school start times in Basel in 2014 and 2015 took place within a period of major societal change regarding electronic and social media use. Adolescents have substantially increased their time spent online between 2010 and 2016 (Waller et al., 2016), and this is supposed to have decreased their sleep duration (Twenge, Krizan, & Hisler, 2017). In conjunction with such social factors, it is also possible that the later bed times reported at t2, i.e. by students in the 9th grade versus their 8th grade reports, may be influenced by changes to the circadian rhythm, leading to a biological preference for staying up late (Roenneberg et al., 2004).

Last, our findings reflected that girls relative to boys reported earlier wake times, a finding supported by previous literature (Mateo et al., 2012; Randler, 2011). In the context of our study, these differences may also reflect the students' cultural backgrounds, given that a large proportion were non-German (e.g. 25% of the students identified as Turkish, Albanian, or Kurdish). Specifically, practices in certain cultures tend to afford greater household-related responsibilities as well as a more authoritarian parenting approach to girls, manifesting in earlier rise times in order to fulfil such tasks before the start of the school day, for instance, preparing breakfast in the morning (Randler et al., 2014). It is possible that SSTc affects students from different cultures – and more specifically girls and boys from different cultures – differently. Therefore, the large proportion of students with minority cultural background may have made it more difficult to find SSTc effects in the current study.

4.1 Strengths and limitations

The following limitations have to be considered when interpreting the current findings. First, the comparison group was drawn from previous year groups of the same schools who left school before SSTc was implemented. It is possible that the sleep patterns of different year-group cohorts were not directly comparable due to changes in adolescents' behaviour during those years (e.g. related to the increase in social media use). Second, since the data were extracted from student feedback surveys conducted at the end of each school year in June, the two measurement time points were one year apart. This may have limited our ability to reveal effects of SSTc, which may be present immediately after the intervention but wear off after some time. Further, during the time of data collection (June), daylight duration was the longest or close to the longest across the year (i.e. sunrise typically around

5.30 am, and sunset typically around 9.30 pm), possibly influencing sleep duration, by for instance, delaying bed times. Future studies may therefore benefit by assessing students' sleep patterns several times across a year. Third, we were constrained to analyse the data from the yearly student satisfaction survey that we were granted access to. Thus, the measures could not be adapted for the current study. All measures used were self-reported, and therefore subject to memory effects. Moreover, the questions on bed and wake up times had a multiple choice format, thereby prohibiting more precise answers, particularly so for very early and very late bed and wake up times (with the earliest and latest option for weekday bedtime being '*before 9:30 pm'* and 'after 11:30 pm' respectively, and the earliest and latest option for weekday wake up time being '*before 6:00 am'* and 'after 7:00 am', respectively). Therefore, it is possible that the effects of SSTc regarding both bed and wake up times may not have been measured with sufficient sensitivity, possibly resulting in ceiling or floor effects. Due to the multiple choice format to assess bedtimes and wake up times, we could also only infer an estimated time spent in bed, which is only a crude measure that may not reflect student's actual sleep duration properly.

## 5. Conclusion

Results from our analyses suggest that the impact of delaying school start times by 20 minutes on adolescents' sleep and wellbeing is debatable, as the observed delays in wake up times were paralleled by concomitant delayed bedtimes, while no positive effects could be observed on behavioural persistence, daytime tiredness, and positive attitude towards life. The divergence between the current study's results and previous empirical evidence suggesting a positive impact of delaying school start times on the sleep behaviour and mental wellbeing of adolescents (Boergers et al., 2014; Minges & Redeker, 2016; Owens, 2014; Perkinson-Gloor et al., 2013; Wolfson et al., 2007) may reflect differences in the length of the school start times delay studied (*i.e.* ≥ 25 minutes vs. only 20 minutes in the current study), and/or recent societal changes regarding adolescents' electronic and social media use during evenings and their effects on sleep behaviour. Future studies should therefore account for these factors, in order to enable researchers, policy-makers and the general public to fully understand the challenges, implications, and benefits of delaying school start times as a strategy for improving adolescent sleep and mental wellbeing outcomes.

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