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CLINICAL REVIEW

Associations of weekday-to-weekend sleep differences with academic performance and health-related outcomes in school-age children and youths

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S U M M A R Y

Weekday-to-weekend sleep discrepancy is a common phenomenon in school-age children and youths. However, the effects of weekday-to-weekend sleep differences remain unclear. A systematic review that included 72 observational studies was conducted to examine the association of weekday-to-weekend differences in bedtime, rise time, mid-point of sleep and sleep duration with academic performance and health-related outcomes in children and youths. Weekday-to-weekend difference in sleep timing (e.g., bedtime) was associated with poorer academic performance and depressive symptoms in in youths, particularly secondary school students, and a higher risk of substance use as well as overweight/obesity in the overall samples. In addition, weekday-to-weekend difference in sleep duration showed a modest association with poorer academic performance and depressive symptoms in the overall samples, as well as a higher risk of overweight/obesity, particularly in Asian children and youths. Albeit limited evidence, greater sleep differences were related to an increased risk of behavioral problems and suicidality. Findings on the associations between weekday-to-weekend sleep differences and specific cognitive abilities, anxiety, and cardiometabolic risks were limited and inconclusive. Longitudinal and experimental studies utilizing objective sleep measures are recommended to further examine the impacts of weekday-to-weekend sleep differences on mental and physical health, and to gain more insight into the mechanisms underlying their associations.

Introduction

Adequate sleep duration and good sleep quality are both critical for maintaining optimal daytime functioning in children and youths, including cognitive abilities, mental wellbeing and physical health [1,2]. However, individual's sleep-wake pattern is not always constant and may vary between weekdays and weekends, and from day to day. Daily variation in sleep, which is sometimes also referred to as night-to-night sleep variability or daily intra-individual variability, is common, especially during holidays in school-age children and youths [3]. Meanwhile, sleep differences between weekdays and weekends are increasingly prominent during the school terms in the young populations, and may largely contribute to daily sleep variability especially during school terms. For example, daily variability in sleep duration across a week is around 1.5 h in adolescents [4], whilst the amount of weekend catch-up sleep in adolescents could be up to one to three hours [5,6]. In addition, approximately 35–40% of secondary school students in the US reported weekend sleep extension over 2 h [5]. The average weekend sleep extension was reported to be around 3 h in high school students in Korea [6]. As such, weekday-to-weekend sleep differences may be of a particular concern for this age group.

A variety of environmental and psychosocial factors may contribute to the weekday-to weekend sleep differences (e.g., shorter weekday sleep duration, weekend oversleep, and misaligned sleep timing between weekdays and weekends) in the student populations, including early school start time, heavy

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Abbreviations

BMI	Body mass index
BTd	Bedtime difference
CPT	Continuous performance task
CRP	C-reactive protein
DLMO	Dim light melatonin onset
fMRI	Functional magnetic resonance imaging
IQ	Intelligence quotient
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
RTd	Rise time difference
SDd	Sleep duration difference
SJL	Social jetlag
WHO	World Health Organization

homework burden, and increased extracurricular and social activities [7]. In addition, differences in the sleep-wake pattern between weekdays and weekends in the young population may be linked to the developmental changes in sleep and circadian rhythm coupled with psychosocial factors. An increase in eveningness (i.e., a circadian preference characterized by an inclination for rest and activity later in the day) is common in adolescents due to the intrinsic circadian delay associated with the pubertal development [8]. This eveningness tendency may also lead to larger weekday-to-weekend sleep differences in adolescents as a result of the mismatch between their endogenous circadian timing and environmental demands (e.g., early school start times). Differences in sleep timing (e.g., bedtime, rise time, the mid-point of sleep) between the nights on a workday and a free day may simulate the effects of jet lag, which is therefore known as ‘social jetlag.’ Social jetlag is typically reflected by the differences in the sleep timing between weekdays and weekends, especially for children and adolescents, because their sleep schedule tends to be less dictated by social obligations (e.g., attending school) during weekends as compared to weekdays. Greater weekday-to-weekend difference in sleep timing is also commonly seen among individuals with evening chronotype [9]. Differences in weekday and weekend sleep tend to peak during adolescence and early adulthood, whilst reducing with increasing age [10].

Growing research suggested that sleep variability might have potential adverse impacts on daytime functioning. In particular, daily intra-individual sleep variability has been reported in association with several adverse health-related outcomes. In Bei et al.'s review of the findings in the general population, daily sleep variability was consistently found to be associated with the risk of mental health problems, including depression and bipolar disorders. However, the relationship between daily sleep variability and cognitive functioning remained inconclusive [11]. In a recent review focusing on children and adolescents, Becker et al. reported that there was some, albeit limited, evidence to suggest a link between daily sleep variability and poor daytime functioning in children and adolescents, such as increased mood symptoms and behavioral problems. However, the findings on the associations of daily sleep variability with academic performance, cognitive functioning, and metabolic regulations were mixed [4]. Whilst the two existing reviews examined the evidence on the effects of day-to-day sleep variability, it remained unclear how weekday-to-weekend sleep differences might affect the health-related outcomes. Previous cross-sectional community-based studies have suggested the benefits of weekend sleep extension on improving cognitive performance and of ameliorating the risk of overweight/obesity in children and adolescents [12,13]. Nonetheless, experimental studies found that weekend catch-up sleep could not fully restore the cognitive impairments after a week's repeated sleep restriction [14,15]. Furthermore, individual's cognitive performance and inflammatory regulation (e.g., cortisol circadian rhythm) were found to gradually deteriorate across the repeated circles of sleep restriction (for five days) and sleep extension (for two days) [15,16], which simulate the typical real-life phenomenon of weekday-to-weekend sleep differences. Given that sleep discrepancy between weekdays and weekends is common in children and youths, there is a need to examine whether weekday-to-weekend sleep differences *per se* have any effect on daytime functioning, including academic performance and other health-related outcomes in this young population.

The current review focused on the child and youth populations with the aims to examine: 1) whether there is an association between weekday-to-weekend sleep differences and academic performance; 2) whether weekday-to-weekend sleep differences are associated with an increased risk for adverse health-related outcomes, such as poor cognitive functioning, mood disturbances, behavioral problems and substance use, as well as poor metabolic-related outcomes.

Methods

This study followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The protocol of this systematic review was registered in PROSPERO (www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42016047899).

Search strategy

The following electronic databases were searched: PubMed, EMBASE, and PsycINFO. Records from the inception of each database to March 1st, 2018 were searched using the following keywords: (“sleep” AND “weekend*”) OR (“social jetlag” OR “social jet lag” OR “social jet-lag”) OR ((“sleep” AND “compensation”) OR (“catch-up” AND “sleep”) OR (“catch up” AND “sleep”). As multiple outcome measures were included, the search terms describing particular outcomes were not applied. The initial search was not limited to a specific type of study design, age group or publication language.

Two reviewers independently assessed the eligibility of the studies by reviewing the abstracts and full text, extracted the data and examined the quality of the included studies. Disagreements were resolved through the discussion with a third reviewer.

Selection criteria

Search results were imported into Covidence for duplicate screening, abstract and full-text screening. Studies were included if they met the following inclusion criteria: 1) English language peer-reviewed studies; 2) Naturalistic observational studies (reviews, commentaries, experimental studies were not included); 3) Conducted in school-age children and youths, which included the samples recruited from primary schools, secondary schools, colleges and community (in order to cover a wider developmental range, studies conducted in the samples with a mean age within 6–24 y old were included, according to the World Health Organization (WHO)'s definition of children and youths); 5) Reported the differences in any sleep parameters (e.g., bedtime, rise time, mid-point of sleep, sleep duration) between weekdays and weekends; 6) Included one or more outcome measures, such as academic performance, cognitive functioning, mental health and physical health. This review focused on the typical weekday-weekend sleep differences during school terms. As such, some special conditions were not considered and included for this review, such as the differences in sleep between school term/school days and long holidays. The exclusion criteria were set as follows: 1) studies that involved shift workers or focused on jetlag; 2) grey literature (e.g., conference abstracts); 3) studies conducted in the special clinical populations (e.g., patients with schizophrenia or asthma).

Data extraction

Data extraction was conducted using Microsoft Excel. The following information was extracted: study characteristics (e.g., authors, publication year, study design, country, sample size, age), sleep parameters, key outcome measures, and major findings regarding weekday-to-weekend sleep differences.

Data synthesis & statistical analysis

A meta-analysis was conducted if there were at least three eligible studies that investigated the target outcome(s) and reported an effect size measure that could be converted to r, which was most commonly reported in the observational studies. The results were pooled according to weekday-to-weekend differences in bedtime, rise time, mid-point of sleep and sleep duration. Meta-analysis was not conducted if there was substantial heterogeneity regarding study design (e.g., cross-sectional vs. longitudinal) and definitions of outcome measures (e.g., withdrawal vs. aggression vs. risky behaviors). Effect sizes from unadjusted analysis or adjusted analysis with minimum covariates were extracted and pooled. For the studies that did not report correlation coefficients, we converted other effect sizes into r for analysis. For example, correlation coefficients from two-group comparison were calculated from the group mean, standard deviation and number of observations. For the studies that compared more than three groups (e.g., grade A, B, C and D), we used the mean and standard deviation of the two most-extreme groups for calculation [17]. The effect size of the correlation between two ordinal variables was converted from the frequency tables to correlation coefficient [17]. Odds ratios and regression coefficients were first converted into Cohen's d and subsequently converted into r [18].

Data synthesis was conducted using Microsoft Excel, and meta-analysis was carried out using R (version 3.3.3) and the metafor package. A random-effects model was used because considerable heterogeneity was expected. The Q and I^2 statistics were calculated as the indicators of heterogeneity. An I^2 value over 75% and significant Q statistic indicated high heterogeneity. Publication bias was tested by inspecting a funnel plot and using Egger's test. Asymmetric funnel plot indicated by significant Egger test suggested the possibility of publication bias (Supplementary Figures).

Sensitivity analysis was conducted if high heterogeneity was identified and at least three eligible studies were available, whilst: 1) limiting the analyses to the studies that reported unadjusted associations; 2) excluding early studies (e.g., published before 2000); 3) limiting the analyses to the studies that adopted the same outcome measures (e.g., same questionnaire). Subgroup analyses were further carried out in the more homogenous groups of studies based on the sensitivity analyses. Two baseline characteristics were examined: 1) the type of samples, i.e., school-age children (defined as mean age between 6 and 12 y), youths (defined as mean age above 12 y, including secondary school students and college students); 2) countries/regions where the studies were conducted, e.g., Asian vs. non-Asian regions.

Quality assessment

Quality assessment of the included observational studies was performed independently by two authors based on a modified scale [11]. Specific objectives or hypotheses, sample representativeness, sample size justification, quality of the sleep measures (e.g., by subjective report or objective measurement), timeframe of the sleep measures, quality of outcome measures, and quality of inference and conclusion were rated additionally for all the included studies. Agreement between two raters was good (intra-class correlation coefficients for the absolute agreement was 0.77).

Results

Search results

The search strategy yielded 2808 papers for initial screening (Fig. 1). A total of 72 studies remained in the final review. Included studies were published from 1998 to 2018, and the majority of the included studies (n = 65) were published after 2010.

Characteristics of the included studies

Characteristic of the included studies are summarized in Tables 1–5. Weekday-to-weekend differences in different sleep parameters, including bedtime, rise time, mid-point of sleep and sleep duration were extracted and reviewed. In some studies, the concept of 'social jetlag' was used to refer to the difference in either bedtime or rise time between weekdays and weekends, whilst in some other studies, 'social jetlag' was used to refer to the difference in mid-point of sleep between weekdays and weekends. Different terms were used across studies to describe the difference in sleep duration between weekdays and weekends, such as 'weekend catch-up sleep', 'weekend oversleep' and 'sleep compensation.' In order to minimize the confusion caused by the use of different terminologies, we summarized the studies based on the following four key sleep parameters respectively: difference in bedtime (BTd), difference in rise time (RTd), difference in mid-point of sleep (social jetlag, SJL) and difference in sleep duration (SDd). Weekday-to-weekend sleep difference was calculated by either subtracting weekday sleep from weekend sleep or the absolute difference between the two parameters. Detailed sleep difference indicators used are specified in Tables 1–5

Most studies reviewed (67%) were conducted in the youths recruited from secondary schools. Among the 11 studies that included school-age children as the majority of the samples, seven studies reported metabolic-related outcomes and only one study reported the outcome of cognitive functioning/academic performance. There were 15 studies conducted in Asian countries/regions, including Korea, Hong Kong, Macau, Taiwan and Mainland China, and 57 studies conducted in non-Asian countries/regions, including United States, Canada, Argentina, Brazil, Chile, United Kingdom, Germany, France, Spain, Poland, Portugal, Norway, Finland, Switzerland, Turkey, Croatia, Russia, Saudi Arabia, Australia and New Zealand.

The results of the quality assessments are shown in Fig. 2. More than 90% of the articles have explicitly stated their aims or hypotheses, and 60% of them reported specific aims related to weekday-to-weekend sleep differences; most studies were conducted in a representative sample. Several limitations were noted in the studies reviewed: 1) most epidemiological studies did not report the sample size estimation (94.4%); 2) the most commonly used sleep measurement was questionnaires (91.7%); 3) most studies did not report the timeframe (e.g., past two-week vs. past one-month) of the self-report scales used to measure sleep.

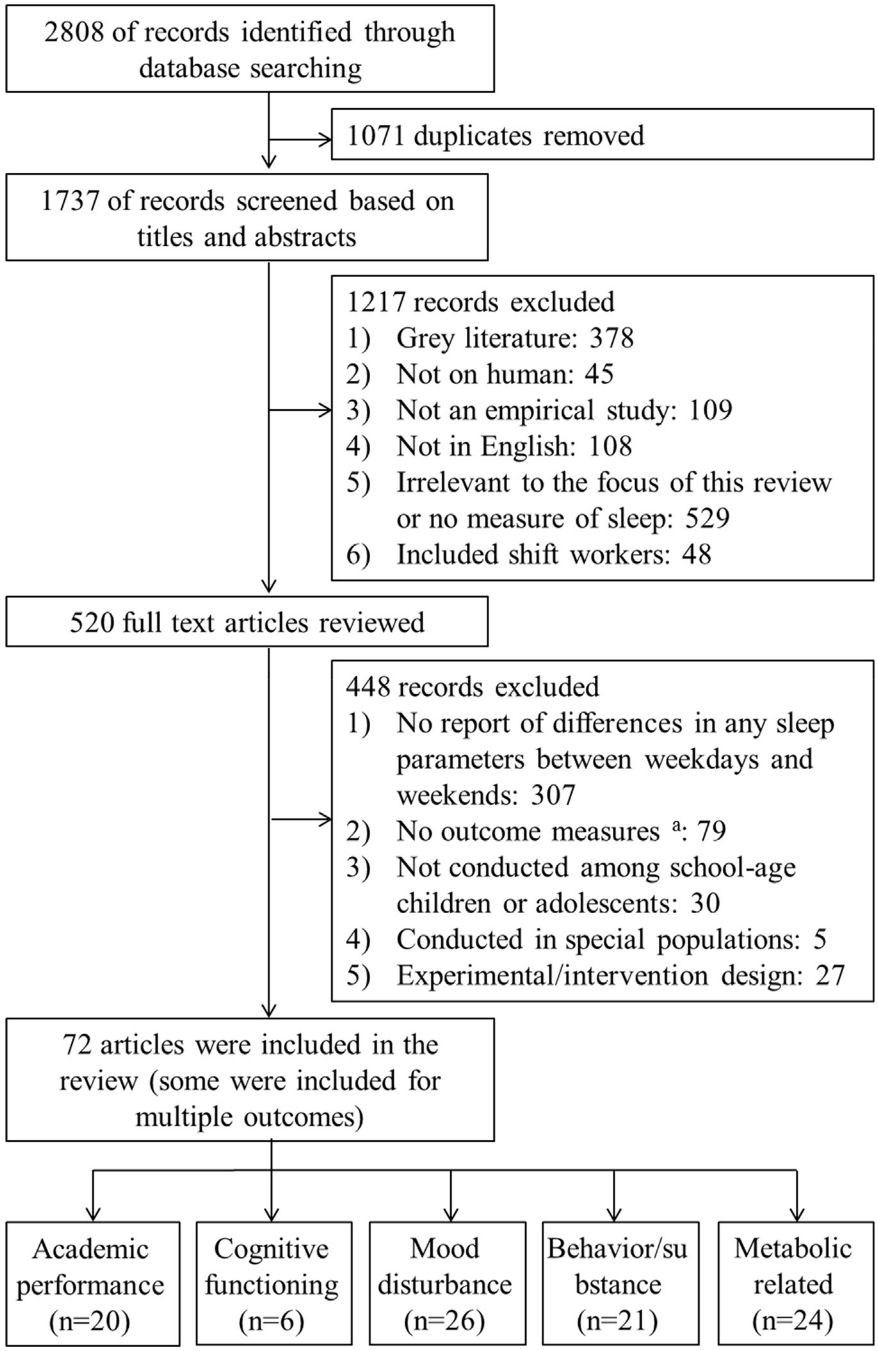

Fig. 1. Flowchart for the study selection.
a. Studies examined the correlates of weekday-to-weekend sleep differences such as socio-demographic factors, sleep features, circadian and seasonality (e.g., daylight saving time) were not included in the current review.

Academic performance (n = 20)

Differences in bedtime and rise time. There were nine studies that measured the association between BTd and academic performance [19–27]. The pooled results of all the studies showed a significant association between BTd and academic performance ($r = -0.15$, $p < 0.001$, Fig. 3A). Due to a high heterogeneity indicated ($I^2 = 93.57\%$), sensitivity and subgroup analyses were conducted (Table S1). Subgroup analysis showed that greater BTd was significantly associated with poorer academic performance in the secondary school students ($r = -0.18$, $p < 0.001$), but was not significantly associated with academic performance in the college students ($r = -0.06$, $p = 0.109$). Moreover, one study explored the effect of weekday-to-weekend sleep differences on school performance and found that larger BTd was related to poorer school attendance in the secondary school students [28].

Given that there were only two studies that investigated the association between RTd and academic performance, a meta-analysis was not conducted. One study reported that larger RTd was associated with better academic performance in the secondary school students [23], whereas the other study found that larger RTd was related to poorer academic performance in the college students [27].

Social jetlag (SJL). The pooled results from four out of five studies suggested a significant negative correlation between SJL and

Table 1
Characteristics and main findings of the included studies regarding academic performance.

Author & year	Meta	Design	Country	Setting	N	Age	Sleep measure	Sleep discrepancy	Outcomes measure	Covariates	Results
Bahammam et al., 2012 [26]	Y	X	Saudi Arabia	College/ University	495	20.4 (1.1)	2w diary, 3d actiwatch	BT	Self-report GPA	NA	BTd GPA ≥ 3.5 vs. GPA<3.5: 1.66 ± 1.42 vs. 1.79 ± 1.46, p = 0.45
Chung & Cheung, 2008 [19]	Y	X	Hong Kong	Secondary school	1629	12–19	Questionnaire	BT, SD	Self-report academic performance	NA	BTd: excellent < good < marginal (F = 12.6, p < 0.001) SDd was not related with academic performance
Díaz-Morales & Escribano, 2015 [29]	Y	X	Spain	Secondary school	796	14.1 (1.5), 12–16	Questionnaire	SJL	GPA	NA	SJL ≥ lower GPA
Haraszti et al., 2014 [32]	Y	X	Germany	College/ University	753 (247)	21.2 (3.1), 18–35	Questionnaire	SJL	Weekly & final grade	Sex, time of weekly test and faculty	SJL ≥ lower weekly grade (Beta = −1.81, p = 0.028) SJL was not related with final grade (Beta = −0.17, p = 0.871)
Hysing et al., 2015 [28]	N	X	Norway	Secondary school	8347	17, 16–19	Questionnaire	BT	School attendance	Age, gender, parental education and income level, and depressive symptoms	BTd ≥ more school absence BTd 2–3 h vs. <2 h: ORcrude = 1.02 (0.86–1.20), ORadj = 1.05 (0.88–1.25) BTd 3–4 h vs. <2 h: ORcrude = 1.49 (1.21–1.85), ORadj = 1.56 (1.25–1.94) BTd >4 h vs. <2 h: ORcrude = 2.26 (1.80–2.85), ORadj = 2.20 (1.72–2.81)
Hysing et al., 2016 [20]	Y	X	Norway	Secondary school	7789	16–19	Questionnaire	BT	GPA	Age, gender, parental education and family affluence	BTd ≥ lower GPA BTd 2–3 h vs. <2 h: ORcrude = 1.19 (1.05–1.35), ORadj = 1.13 (0.99–1.29) BTd 3–4 h vs. <2 h: ORcrude = 1.88 (1.60–2.21), ORadj = 1.66 (1.40–1.96) BTd >4 h vs. <2 h: ORcrude = 3.71 (3.09–4.44), ORadj = 2.95 (2.44–3.58)
Kolomeichuk et al., 2016 [31]	Y	X	Russia	Primary & secondary school	1666	10–18	Questionnaire	SJL	Self-report grade (5 scale)	Age, gender, average sleep duration, chronotype	Correlation: SJL ≥ poor grade (r = −0.12, p < 0.001) Regression: SJL not significant (Beta = −0.01, p = 0.819)
Mak et al., 2012 [23]	Y	X	Hong Kong	Secondary school	22,678	12–18	Questionnaire	BT, RT, SD	Self-report grade (5 scales)	Sex, age, family affluence, exercise, smoking, drinking, body mass index, and school effect, sleep problem	BTd > 2 h ≥ poor academic performance (OR = 1.46 [1.29–1.65]) RTd 1–2 h and >2 h ≥ less likelihood of poor academic performance (1–2 h OR = 0.64 [0.56–0.73], >2 h OR = 0.69 [0.59–0.80]) SDd >2 h ≥ poor academic performance (OR = 1.17 [1.03–1.33])
Matos et al., 2016 [35]	Y	X	Portugal	Secondary school	3164	14.9 (1.3), 12–18	Questionnaire	SD	Health Behavior in School-Aged Children (5 scale rating)	Difficulties in sleep initiation, fatigue, school related factors	Academic achievement, disliking school were not related with SDd >2 h Study pressure ≥ more SDd >2 h (Beta = −0.095, p = 0.016) Skipping classes ≥ more SDd >2 h (Beta = −0.131, p = 0.001)
Merdad et al., 2014 [24]	Y	X	Saudi Arabia	Secondary school	1035	14–23	Questionnaire	BT, RT	GPA (3 scales)	Sex	ANOVA: BTd: excellent < very good & good or below (p < 0.001) Regression: lower GPA ≥ greater BTd (Beta = −0.24, p = 0.041)
Mirghani et al., 2015 [27]	Y	X	Saudi Arabia	College/ University	165	22.5 (1.8)	Questionnaire, 2w diary	BT, RT	Grade (A or C)	NA	BTd A vs. C: 1.2 ± 1.8 vs. 1.6 ± 1.7, F = 1.44, p = 0.23 RTd A vs. C: 2.1 ± 2.0 vs. 3.8 ± 2.2, F = 25.03, p < 0.001

(*continued on next page*)

Table 1 (*continued*)

Author & year	Meta	Design	Country	Setting	N	Age	Sleep measure	Sleep discrepancy	Outcomes measure	Covariates	Results
Lee et al., 2015 [38]	Y	X	Korea	Secondary school	50 + 51	16.7 (1.1)	Questionnaire	SD	Self-report academic performance (4 scales), Barratt Impulsiveness Scale (BIS)	Age, sex, sleep duration in weekday, ESS, BDI, chronotype	Correlation: SDd ≥ lower ranking ($r = 0.33$, $p = 0.01$) Regression: overall: SDd ≥ lower ranking (Beta = 0.39, $p = 0.01$) with BISS: SDd ≥ lower ranking (Beta = 0.42, $p < 0.01$) without BISS: SDd not related with academic performance
Lin & Yi, 2015 [33]	N	L (3y)	Taiwan	Secondary school	2472	14.3 (0.5), 14−18 (W2)	Questionnaire	SJL	W3 Subjective report, GPA ranking, number of subjects failed	Sex, SES, sleep duration & problem, W2 conduct problem, W3 defiance attitude	W2 SJL ≥ W3 poor academic performance (Beta = 0.11, $p < 0.01$)
O'Brien & Mindell, 2005 [21]	Y	X	United States	Secondary school	388	16.6, 14−19	Questionnaire	BT, SD	Self-report grade (4 scales)	NA	BTd <1 h (vs. ≥ 2 h) ≥ poor academic performance ($X^2 = 19.39$, $p < 0.001$) SDd <1 h~>2 h ($X^2 = 3.16$, $p > 0.05$)
Önder et al., 2014 [30]	Y	X	Turkey	College/ University	1343	21.0 (1.8), 18−34	Questionnaire	SJL	Cumulative GPA (CGPA)	MSFsc, academic motivations, personality	SJL ≥ lower CGPA (Beta = −0.115)
Pallesen et al., 2011 [34]	Y	X	Norway	Secondary school	1285	16−19	Questionnaire	SD	School grade (6 scales)	NA	Mean grade: SDd >2 h vs. ≤2 h: 3.9 ± 0.9 vs. 4.0 ± 1.0, $p > 0.05$
Perez-Lloret et al., 2013 [37]	Y	X	Argentina	Secondary school	1194	15, 13−17	Questionnaire	SD_{abs}	Academic performance (10 scale teacher rating)	NA	Correlation: SDd ≥ lower math grades ($r = -0.07$, $p = 0.03$), but not language grades ($r = -0.06$, $p = 0.07$)
Singleton & Wolfson, 2009 [25]	Y	X	United States	College/ University	236	18−22	Questionnaire	BT_{abs}, SD_{abs}	CGPA, GPA	Academic aptitude, gender, study year, alcohol consumption, sleep duration, sleep schedule, daytime sleepiness	Correlation: BTd, SDd were not related with CGPA or GPA Regression: BTd, SDd were not related with CGPA
Wolfson & Carskadon, 1998 [22]	Y	X	United States	Secondary school	3120	13−19	Questionnaire	BT, SD	Self-report grade (4 scales)	NA	BTd: A < B < C,D/F (F = 26.53, $p < 0.001$) SDd: A,B,C < D/F (F = 3.32, $p < 0.05$)
Wong et al., 2013 [36]	Y	L (3 sems)	Hong Kong & Macau	College/ University	930	21.7 (2.2), 18−25	Questionnaire	SD	GPA (11 scales)	NA	Time 1: SDd ≥ lower GPA ($r = -0.13$, $p < 0.05$) SDd was not included in the SEM.

Notes. Y = included in the meta-analysis; BT = bedtime; RT = rise time; SJL = social jetlag; SD = sleep duration; -d = difference; NA = not applicable; GPA = grade-point average; ANOVA: analysis of variance; X = cross-sectional study; L = longitudinal study; abs = absolute differences in sleep between weekday and weekend.

Table 2
Characteristics and main finding of the included studies regarding cognitive functioning.

Authors	Meta	Design	Country	Setting	N	Age	Sleep measure	Sleep discrepancy	Outcomes measures	Covariates	Results
Díaz-Morales & Escribano, 2015 [29]	N	X	Spain	Secondary school	796	14.1 (1.5), 12–16	Questionnaire	SJL	Thurstone's Primary Mental Abilities (PMA)	NA	SJL ≥ lower cognitive abilities (spatial rotation, inductive reasoning, numerical and general cognitive ability) Girl: SJL ≥ lower cognitive abilities (vocabulary, spatial rotation, inductive reasoning, numerical and general cognitive ability) Boy: SJL ≥ lower cognitive abilities (inductive reasoning and numerical)
Hasler et al., 2012 [42]	N	X	United States	Community	56	12.3 (0.9), 11–13	4d actiwatch	SJL	Monetary reward (fMRI)	Sex, pubertal stage, and total sleep time	SJL ≥ decreased mPFC and striatal reactivity to reward (reduced regulatory response and reward sensitivity)
Kim et al., 2011 [39]	N	X	Korea	Secondary school	2638	17.3 (0.6), 14–19	Questionnaire	BT, RT, SD	Continuous performance task, divided attention task	Age, sex, depressed mood, and habitual snoring (weekday sleep duration for SDd)	BTd was not related with sustained attention or divided attention RTd ≥ more commission error in sustained attention task (Beta = 0.16, $p < 0.05$), but was not related with other attention indicators SDd ≥ more omission error (sustained: Beta = 0.48, $p < 0.001$; divided: Beta = 0.29, $p < 0.05$), more commission error (sustained: Beta = 0.16, $p < 0.05$; divided: Beta = 0.18, $p < 0.05$)
Kuula et al., 2015 [12]	N	X	Finland	Community	354	12.3 (0.5), 11–13	8n actiwatch	SD	WISC-III, NEPSY-II memory, CPT, WCST, TMT	Age, parental SES, BMI, pubertal development, and maternal glycyrrhizin consumption	Girl: SDd ≥ longer RT but better performance in the Similarities subtest of the WISC-III (verbal intelligence) Boy: SDd ≥ higher D-prime in CPT (better sustained attention)
Panev et al., 2017 [41]	N	X	Russia	Community	1008	14–25	Questionnaire	SJL	Raven's Standard Progressive Matrices test (RPM)	Age, gender, academic performance and place of residence	In whole sample, SJL was not related with non-verbal IQ In evening type adolescent, SJL ≥ 2 h ≥ lower non-verbal IQ
Warren et al., 2016 [40]	N	L (1yr)	United States	Primary school	709	4th–5th grade	Questionnaire	BT, RT	Behavioral Rating Inventory of Executive Function-Self-Report (BRIEF-SR)	Gender, ethnicity, and socioeconomic status	BTd, RTd at 4th grade ≥ lower 5th grade BRIEF scores

Notes. N = not included in the meta-analysis; BT = bedtime; RT = rise time; SJL = social jetlag; SD = sleep duration; -d = difference; NA = not applicable; WISC-III = Wechsler intelligence scale for children version 3; CPT = continuous performance task; WCST = Wisconsin card sorting test; TMT = trial making test; IQ = intelligence quotient; X = cross-sectional study; L = longitudinal study; abs = absolute differences in sleep between weekday and weekend.

Table 3
Characteristics and main finding of included studies regarding mood-related disturbances.

Authors	Meta	Design	Country	Setting	N	Age	Sleep measure	Sleep discrepancy	Outcomes measures	Covariates	Results
Bakotic et al., 2016 [45]	Y	X	Croatia	College/University	1052	20.8 (1.7), 18–25	Questionnaire	BT	Kandel & Davies depressive mood scale (DMS)	Age, gender	Correlation: BTd ≥ lower depressive mood ($r = -0.105$, $p < 0.01$) Mediator analysis: eveningness ≥ larger BTd ($a = -0.03$, $p < 0.001$) BTd ≥ lower depressive mood ($b = -0.11$, $p = 0.009$)
Borisenkov et al., 2015 [52]	N	X	Russia	Secondary school	3435	14.8 (2.6), 10–20	Questionnaire	SJL	Seasonal Pattern Assessment Questionnaire	NA	Girl: SJL: SAD > non-SAD, $F = 3.1$, $p = 0.044$ Boy: SJL was not related with SAD
Chung & Cheung, 2008 [19]	Y	X	Hong Kong	Secondary school	1629	14.8 (1.7), 12–19	Questionnaire	SD	Perceived stress scale (PSS)	NA	SDd ≥ higher PSS score ($r = 0.14$, $p < 0.001$)
De Souza & Hidalgo, 2014 [50]	N	X	Brazil	Community	351	14.7 (1.9), 12–21	Questionnaire	SJL	Beck depression inventory (BDI)	Age, sex, classes' schedule, sunlight exposure, sleep duration, midpoint of sleep on free/ school days	Correlation: SJL was not related with BDI ($r = 0.07$, $p = 0.193$) SJL: BDI ≥ 10 ~ BDI<10: 1.8 ± 1.4 vs. 1.6 ± 1.5, $t = -0.68$, $p = 0.501$ Regression: SJL ≥ BDI (Beta = 0.057, $p < 0.05$) when controlling for MSF SJL was not related with BDI when controlling for MSW
Díaz-Morales, 2016 [55]	N	X	Spain	Secondary school	1406	14.0 (1.7), 12–16	Questionnaire	SJL_{abs}	State-trait anxiety inventory (STAI-T)	Age	Correlation: SJL was not related with anxiety ($r = 0.03$, $p > 0.05$) The interaction between gender and anxiety was not a significant predictor for SJL ($F = 1.49$, $p > 0.05$)
Hasler et al., 2014 [56]	N	L (5y)	United States	Secondary school	696	16.2 (1.5), 12–19	Questionnaire	SD_{abs}	Beck depression inventory (BDI)	NA	**Baseline** SDd was not related with depression ($F = 0.35$, $p = 0.55$)
Haynie et al., 2018 [51]	N	L (3y)	United States	Secondary school	2785	10th to 12th grade	Questionnaire	SJL_{abs}	Modified depressive scale	Gender, race, family structure, parent education, parental monitoring	W1: SJL ≥ more depressive mood ($r = 0.11$, $p < 0.01$) The significance remained after controlling for potential confounders
Hysing et al., 2015 [47]	N	X	Norway	Secondary school	9875	17.8 (0.8), 16–19	Questionnaire	BT	Self-harm questionnaire	Age, gender, parental education, SES, mood, eating disorder, ADHD symptoms	No self-harm vs. self-harm: BTd >2 h: 22.0% vs. 35.8%, $p < 0.001$ Regression: BTd>2 h ≥ self-harm (crude OR = 1.20, 95% CI = [1.02, 1.40]; adjusted OR = 1.29, 95% CI = [1.09, 1.53])
Jankowski 2015 [54]	N	L (3w)	Poland	College/University	117	22.2 (1.9), 19–31	Questionnaire	SJL	Satisfaction with life scale (SWLS), UWIST mood adjective check list (UMACL)	Photoperiod, chronotype	Correlation: SJL ≥ tense arousal ($r = 0.18$, $p < 0.05$) SJL was not related with hedonic tone, energetic arousal or life satisfaction Regression: SJL was not related with life satisfaction or mood

Kang et al., 2014 [59]	N	X	Korea	Secondary school	4145	15.3 (1.5), 7th –10th grade	Questionnaire	SD	Self-injury or suicidal attempts, suicidal ideation questionnaire (SIQ)	Age, gender, time in private educational institute, academic record, BDI	SDd ≥ higher SIQ scores (Beta = 0.48, $p = 0.009$) suicide attempts or self-injury (OR = 1.13, 95% CI = [1.03 –1.25]) SIQ or self-injury was not related with weekday sleep duration
Lee et al., 2012 [43]	Y	X	Korea	Secondary school	8010	16.7 (1.1), 7th –11th grade	Questionnaire	BT, RT, SD	Beck scale for suicidal ideation (SSI), BDI	Regression 1: Age, sex Regression 2: R1+ insomnia, snoring, ESS, BDI (for SSI)	BTd ≥ higher BDI in R1(Beta = 0.26, $p < 0.001$), but not in R2 higher SSI in R1(Beta = 0.15, $p < 0.01$), but not in R2 RTd ≥ higher BDI in R1 and R2 (Beta1 = 0.30, $p < 0.001$; Beta2 = 0.09, $p = 0.03$) higher SSI in R1 and R2 (Beta1 = 0.24, $p < 0.001$; Beta2 = 0.07, $p < 0.01$) SDd ≥ higher BDI in R1(Beta = 0.20, $p < 0.001$), but not in R2 higher SSI in R1 and R2 (Beta1 = 0.19, $p < 0.001$; Beta2 = 0.07, $p < 0.01$)
Lee et al., 2015 [38]	N	X	Korea	Secondary school	50 + 51	16.7 (1.1)	Questionnaire	SD	BDI	NA	SDd ≥ higher BDI ($r = 0.30$, $p < 0.01$) With BIISS > without BISS: 13.7 ± 6.5 vs. 8.5 ± 5.9, $F = 4.23$, $p < 0.001$
Lee et al., 2016 [57]	Y	X	Korea	Secondary school	3785	15.3 (1.5), 11–18	Questionnaire	SD	BDI	Age, gender	Partial correlation: SDd ≥ higher BDI ($r = 0.052$, $p = 0.001$) Male: SDd ≥ higher BDI ($r = 0.086$, $0 < 0.001$) Female: SDd ≥ lower BDI ($r = -0.068$, $p = 0.007$)
Levenson et al., 2015 [48]	N	L (10y)	United States	Community	47 (BP/OB) 386 (non-BP/OB) 301 (control)	6–18	Questionnaire (parent report)	BT, RT	Clinical interview (SCID, K-SADS)	NA	BTd was not related with bipolar family history/diagnose RTd was low in control ($F = 3.29$, $p = 0.04$) BTd/RTd could not predict the conversion to BP of child with BP parent
Lin & Yi, 2014 [33]	N	L (3y)	Taiwan	Secondary school	2472	14.3 (0.5), 14–18	Questionnaire	SJL (W2)	W3 Emotion well-being	Sex, SES, sleep duration & problem, W2 conduct problem, W3 defiance attitude	SJL was not related with W3 conduct problem or emotional well-being
Lin et al., 2018 [58]	N	L (6y)	Taiwan	Secondary school	1747	7th to 12th grade	Questionnaire	SD	Depressive mood (modified CES-DC)	Time, gender, parental education level, BMI, academic stress, physical activity, substance use, commuting	Higher depressive mood ≥ greater SDd (B = 0.89, $p < 0.01$)

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Table 3 (*continued*)

Authors	Meta	Design	Country	Setting	N	Age	Sleep measure	Sleep discrepancy	Outcomes measures	Covariates	Results
Miller et al., 2016 [49]	N	L (4y)	United States	Secondary school	829	12.6 (1.02) T1	Questionnaire	BT	Social anxiety	Age, gender, internalizing and externalizing behaviors	BTd was not related with social anxiety
O'Brien & Mindell, 2005 [21]	Y	X	United States	Secondary school	388	16.6, 14–19	Questionnaire	BT, SD	Depressive mood scale (DMS)	NA	BTd ≤ 1 h (vs. ≥ 2 h) did not differ in depressive mood SDd <1 h (vs. >2 h) did not differ in depressive mood
Paiva et al., 2015 [61]	N	X	Portugal	Secondary school	3476	14.9, 12.5–19	Questionnaire	SD	Health related quality of life (Kidscreen 10)	NA	Kidscreen 10: SDd >3 h vs. ≤3 h: 37.99 ± 5.66 vs. 38.80 ± 5.85, F = 9.12, p = 0.003
Pallesen et al., 2011 [34]	N	X	Norway	Secondary school	1285	16–19	Questionnaire	SD	Hospital anxiety and depression scale (HADS)	NA	SDd >2 h was not related with HADS scores.
Pasch et al., 2010 [46]	N	X	United States	Secondary school	242	16.4, 10–16	Questionnaire	BT, RT, SD	Depressive mood scale (DMS)	Sex, school grade, SES, BMI, pubertal development, parent's education, sleep duration	BTd, RTd, SDd were not related with depressive symptoms when controlling for potential confounding factors
Sheaves et al., 2016 [53]	N	X	United Kingdom	College/University	1403	21, 20–23	Questionnaire	SJL	Paranoia & hallucination (SPEQ), mania (MDQ), depression & anxiety (DASS-21)	NA	SJL was not related with overall risk of sever mental illness (X^2 = 0.19, p = 0.910), or any psychiatric symptoms
Troxel et al., 2016 [60]	N	L (X)	United States	Secondary school	2485	17.3 (0.7)	Questionnaire	SD	Mental health inventory (MHI-5)	Energy drink use, age, sex, race, maternal education, SES, intervention	Regression: Higher MHI-5 score (better mental health) ≥ lower SDd (beta = −0.01, p < 0.01)
Wolfson & Carskadon, 1998 [22]	Y	X	United States	Secondary school	3120	13–19	Questionnaire	BT, SD	Depressive mood scale (DMS)	Age	BTd >2 h vs. <1: Girl: more depressive symptoms (F = 3.89, p < 0.05); Boy: ns. SDd >2 h vs. <1 h: both genders: ns.
Wong et al., 2013 [36]	Y	L (3 sem)	Hong Kong & Macau	College/University	930	21.7 (2.2), 18–25	Questionnaire	SD	WHOQOL (physical), DASS, self-esteem	See findings	T1 SDd ≥ T3 lower self-esteem (B = −0.085, p = 0.012, controlling for T1 self-esteem) T1 SDd ≥ T2 more depressive symptoms (r = 0.11, p < 0.05) and stress (r = 0.09, p = 0.05), not related with T2 anxiety symptoms. T1 SDd ≥ T3 physical QoL SDd was not included in the structural equation model
Zhang et al., 2016 [44]	Y	X	United States	Secondary school	10,123	13–18	Questionnaire	BT, SD	Diagnostic interview for mental	Age, sex, and race/ethnicity	BTd >2 h vs. 1–2 h ≥ increased odds of depressive mood (OR = 1.57), suicidality

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disorder (DSM-IV), parent report behavioral problem	(OR = 1.92) and poor perceived mental health (OR = 1.51) SDd >2 h vs. 0–2 h ≥ increased odds of depressive mood (OR = 1.67), suicidality (OR = 1.75) and poor perceived mental health (OR = 1.42) SDd ≤ 0 h vs. 0–2 h ≥ increased odds of anxiety (OR = 1.39)

Notes. Y = included in the meta-analysis; N = not included in the meta-analysis; BT = bedtime; RT = rise time; SJL = social jetlag; SD = sleep duration; –d = difference; NA = not applicable; BDI = Beck Depression Inventory; CES-DC = Center for Epidemiological Studies Depression Scale for Children; SAD = seasonal affective disorder; BP/OB = bipolar parent/offspring bipolar; W = wave; T = time; SES = socio-economic statues; ADHD = attention deficit hyperactivity disorder; SCID = Structured Clinical Interview for DSM-IV; K-SADS = Schedule for Affective Disorders and Schizophrenia for School-age Children; SPEQ = Specific Psychotic Experiences Questionnaire; MDQ = Mood Disorder Questionnaire; DASS = Depression, Anxiety, and Stress Scales; WHOQOL = The World Health Organization Quality of Life; OR = odds ratio; X = cross-sectional study; L = longitudinal study; abs = absolute differences in sleep between weekday and weekend.

emic performance in the secondary school students and college students ($r = -0.14$, $p < 0.001$, Fig. 3B) [29–32]. The was one longitudinal study, which was not included in this meta-analysis, also reporting that greater social jetlag at baseline was predictive of poorer academic performance one year later [33].

Difference in sleep duration. There were 10 studies that measured the association between SDd and academic performance [19,21–23,25,34–38]. The pooled results of all these studies suggested that larger SDd was correlated with poorer academic performance ($r = -0.08$, $p < 0.001$; Fig. 3C). Since high heterogeneity was indicated ($I^2 = 81.09\%$), sensitivity and subgroups analyses were conducted. The results showed that the association remained significant (e.g., when the included studies were limited to those reporting unadjusted association or to those recent publications) (Table S2).

Cognitive functioning (n = 6)

Differences in bedtime and rise time. There were only two studies that examined the association between BTd/RTd and cognitive functioning. As such, a meta-analysis was not conducted. One study found mixed effects of BTd and RTd on sustained attention in the secondary school students. In particular, students with larger RTd were found to make more commission errors but not omission errors on the continuous performance task (CPT, a task designed to assess attention-related problems), whilst BTd was not found to be related to sustained attention as measured by CPT. Neither BTd nor RTd was associated with the performance on the divided attention task [39]. Moreover, larger BTd and RTd were found to be associated with poorer executive functions as measured by self-report scale (i.e., Behavioral Rating Inventory of Executive Function) in children [40].

Social jetlag. There were three studies that examined the effects of SJL on cognitive functioning using various outcome measures. As such, a meta-analysis was not conducted. In one study, SJL was reported to be associated with overall cognitive functioning (e.g., as measured by Thurstone's Primary Mental Abilities) as well as some specific cognitive abilities in the youths, including spatial rotation, inductive reasoning, and numerical abilities. However, there was no relationship between verbal fluency ability and SJL [29]. Another recent study showed a significant effect of interaction between SJL and chronotype on non-verbal intelligence (IQ). Specifically, SJL >2 h was found to be negatively associated with non-verbal IQ in the youths with evening chronotype but not in those with either morning- or intermediate-type [41]. An fMRI study found that youths with greater SJL showed decreased brain activity in the reward-related regions (i.e., decreased medial prefrontal cortex and striatal activity) whilst performing a monetary reward task [42].

Difference in sleep duration. Due to the limited available studies (n = 2), a meta-analysis was not conducted on the association between SDd and cognitive functioning. Larger SDd was found to be associated with poorer sustained attention and divided attention in the secondary school students, even after adjusting for weekday sleep duration [39]. Gender differences in the effects of SDd on cognitive functioning were reported among the secondary school students. In girls, larger SDd was found to be associated with a speed-accuracy trade-off (i.e., slower response but higher accuracy) on a verbal intelligence task. In boys, larger SDd was related to better sustained attention (i.e., higher D prime value on the CPT) [12].

Table 4
Characteristics and main finding of included studies regarding behavioral problems and substance use.

Authors	Meta	Design	Country	Setting	N	Age	Sleep measure	Sleep discrepancy	Outcomes measures	Covariates	Results
Bakotic et al., 2016 [45]	N	X	Croatia	College/ University	1052	20.8 (1.7), 18–25	Questionnaire	BT	Substance use (cigarette, alcohol, drug)	Age, gender	Correlation: BTd ≥ more substance use ($r = 0.305$, $p < 0.01$) Mediator analysis: eveningness ≥ larger BTd ($a = -0.03$, $p < 0.001$) BTd ≥ more substance use ($b = 0.51$, $p < 0.001$)
Chung & Cheung, 2008 [19]	Y	X	Hong Kong	Secondary school	1629	14.8 (1.7), 12–19	Questionnaire	SD	Cigarette, alcohol use	Age, sex, grade level, body weight, traveling time to school, involvement in part-time work, exercise habit	Correlation: SDd ≥ smoking habit ($r = 0.10$, $p < 0.01$), alcohol use ($r = 0.12$, $p < 0.01$). Regression: smoking habit ≥ SDd (Beta = 0.60, $p < 0.05$)
Hasler et al., 2014 [56]	Y	L (5y)	United States	Secondary school	696	16.2 (1.5), 12–19	Questionnaire	SD_{abs}	Substance use (SCID)	Age, gender, and baseline alcohol symptoms, BDI, insomnia, hypersomnia	**Baseline** SDd AUD- vs. AUD+: 1.18 ± 1.43 vs. 2.14 ± 1.88, $F = 43.54$, $p < 0.001$ **Follow-up** SDd was not related with current alcohol symptom SDd at baseline was predictive for alcohol symptoms at 3- and 5- y (but not 1-y) in participants without AUDs (Beta1 = −0.03, $p = 0.672$; Beta2 = 0.18, $p = 0.008$; Beta3 = 0.16, $p = 0.035$)
Hasler et al., 2017 [65]	N	L (1y)	United States	Community	729	15.9 (2.4), 12–21	Questionnaire	BT, RT	Substance use (Customary drinking and drug use record)	Baseline age, sex, race, parental SES, and psychiatric problems	Baseline: BTd, RTd was not related with alcohol or Marijuana use Follow-up: baseline RTd ≥ more Marijuana use baseline RTd was not related with alcohol use baseline BTd was not related with substance use
Haynie et al., 2018 [51]	N	L (3y)	United States	Secondary school	2785	10th to 12th grade	Questionnaire	SJL_{abs}	Number of alcohol use and heavy episodic drink (once 5 or 4 drinks) in the last 30 days	Gender, race, family structure, parent education, parental monitoring	W2 SJL ≥ W3 alcohol use and heavy episodic drinking W2 alcohol use and heavy episodic drinking ≥ W3 SJL
Kubiszewski et al., 2014 [62]	N	X	France	Secondary school	1422	14.3 (2.7), 10–18	Questionnaire	BT, RT	School bullying, behavioral problem	NA	BTd and RTd were high in bullies (BTd $F = 7.8$, RTd $F = 7.7$, $p = 0.02$) BTd >2 h or RTd ≥ more externalizing behaviors (aggression and antisocial behavior) in bullies Interaction between BTd or RTd and bully was not a significant predictor for externalizing problem
Lemola et al., 2012 [70]	N	X	Switzer-land	Primary school	176	11.6 (0.4), 10–13	Questionnaire	SD_{abs}	Negative interparental conflict (CRSI), child's appraisal (CPIC-Y), self-report aggression (RCPM)	Sex, pubertal status, SES	Correlation: SDd was not related with aggression. Regression: interaction between negative interparental conflict behavior/perceived threat and SDd were significant predictors to aggression (std. Beta = 0.23, $p < 0.01$; std. Beta = 0.19, $p < 0.05$)
Lin & Yi, 2015 [33]	N	L (3y)	Taiwan	Secondary school	2472	14.3 (0.5), 14–18 (W2)	Questionnaire	SJL (W2)	W3 defiant attitude, conduct behavior (W2-4)	Sex, SES, sleep duration & problem, W2 conduct problem, W3 defiance attitude	SJL ≥ W2 conduct problem (Beta = 0.05, $p < 0.01$) SJL ≥ W3 defiant attitude (Beta = 0.038, $p < 0.01$)

Lin et al., 2018 [58]	N	L (6y)	Taiwan	Secondary school	1747	7th to 12th grade	Questionnaire	SD	Smoking, alcohol consumption, betel nut chewing	Time, gender, parental education level, BMI, academic stress, mood, physical activity, commuting	Tobacco smoking ≥ greater SDd ($B = 7.86$, $p < 0.05$) Alcohol consumption and betel nut chewing were not related with SDd
Miller et al., 2016 [49]	N	L (4y)	United States	Secondary school	829	12.6 (1.02) T1	Questionnaire	BT	Substance use (cigarette, alcohol, marijunan), behavioral problem	Age, gender, internalizing and externalizing behaviors	Correlation: BTd ≥ more internalizing problem ($r = 0.10$, $p < 0.01$) and externalizing problem ($r = 0.16$, $p < 0.01$) Regression: BTd was not predictive for substance use
O'Brien & Mindell, 2005 [21]	Y	X	United States	Secondary school	388	16.6, 14–19	Questionnaire	BT, SD	Youth risk taking behavior scale (YRBS)	NA	BTd ≥ 2 h ≥ more safety and sexual behaviors, more substance use No difference in violence behavior SDd >2 h was not related with behavioral problem or substance use
Pan et al., 2012 [71]	Y	X	China	Secondary school	1479	15.5 (1.8)	Questionnaire	SD	Smoking	Region (Macau vs. Guangdong), age, sex, TV or computer use	Regression: smoking ≥ higher SDd (Beta = 1.05, $p < 0.001$)
Pasch et al., 2010 [46]	Y	X	United States	Secondary school	242	16.4, 10–16	Questionnaire	BT, RT, SD	Substance use (alcohol, marijuana),	Sex, school grade, SES, BMI, pubertal development, parent's education, sleep duration	BTd ≥ all risky behaviors (OR ranging from 1.65 to 2.59) RTd ≥ all risky behaviors (OR ranging from 1.65 to 2.60) SDd was not related with any risky behaviors
Pasch et al., 2012 [66]	N	L (2y)	United States	Secondary school	704	14.7, 10–17	Questionnaire	BT, SD	Substance use (cigarette, alcohol, marijuana)	Gender, race, age, parent education, pubertal status, depressive symptoms	**Baseline** BTd, SDd ≥ increased cigarette, alcohol and marijuana use **Follow up** T1 BTd ≥ increased T2 alcohol use (Beta = 0.12, $p < 0.05$) T1 alcohol use ≥ less T2 SDd (Beta = −0.37, $p < 0.05$) T1 marijuana use ≥ more T2 SDd (Beta = 0.37, $p < 0.05$)
Pesonen et al., 2010 [63]	N	X	Finland	Primary school	470	8	3-14d actiwatch	BT_{abs}, RT_{abs}, SD_{abs}	Behavioral problem (CBCL, DSM5-DOS)	Age, gender, illness, parental education level	Correlation: BTd and RTd were not related with parent-rated child behavioral problem SDd ≥ increased father-rated total and internalizing problem, but was not related with mother-rated behavioral problem Regression: SDd ≥ increased total behavior ($B = 0.3$, $p = 0.05$) and internalizing behavior ($B = 0.2$, $p = 0.02$)
Randler, 2008 [64]	N	X	Germany	College/ University	326	24.0 (4.3), 18–49	Questionnaire	RT	Substance use (cigarette)	Age, gender, breakfast habits, coffee & alcohol consumption, chronotype	RTd smoker vs. non-smoker: 2:30 ± 1:39 vs. 2:01 ± 1:07, $t = 2.71$, $p = 0.007$ RTd was significant in the canonical discriminant function separating smoker
Randler & Vollmer, 2013 [68]	N	X	Germany	College/ University	432	23.8 (3.7)	Questionnaire	SJL_{abs}	Aggression behavior	Gender, chronotype, sleep duration	Correlation: SJL ≥ verbal aggression ($r = 0.29$, $p < 0.001$), physical aggression ($r = 0.22$, $p < 0.001$) SJL was not related with anger or hostility MANOVA: SJL ≥ physical aggression

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Table 4 (*continued*)

Authors	Meta	Design	Country	Setting	N	Age	Sleep measure	Sleep discrepancy	Outcomes measures	Covariates	Results
											($F = 6.38$, $p = 0.01$) SEM: SJL ≥ physical & verbal aggression (Beta $= -0.22$, $p < 0.001$) SJL ≥ sleep duration (Beta $= -0.15$, $p < 0.001$) Sleep duration ≥ physical & verbal aggression (Beta $= -0.14$, $p = -0.02$)
Singleton & Wolfson, 2009 [25]	Y	X	United States	College/ University	236	18–22	Questionnaire	BT_{abs}, SD_{abs}	Alcohol consumption	Academic aptitude, gender, study year	Alcohol consumption amount ≥ higher BTd (Beta $= 0.358$, $p < 0.1$); higher SDd (Beta $= 0.155$, $p < 0.05$)
Tavernier et al., 2015 [69]	N	L (3y)	Canada	College/ University	942	19.0 (0.9), 17–25	Questionnaire	SJL_{abs}	Academic adjustment, substance use (alcohol, Marijuana)	Age, gender, parental education and study variables in Time 1	SJL was predicted by perceived morningness-eveningness and substance use measured at the previous time point SJL could not predict academic adjustment and substance use measured at the next time point
Warren et al., 2017 [67]	N	L (2y)	United States	Primary school	709	9–12	Questionnaire	BT, RT	Substance use (self-report)	Mediator: executive function Covariates: gender, ethnicity, baseline age, SES	No direct effects of BTd or RTd on substance use Indirect effects: BTd and RTd at 4th grade ≥ poor executive function at 5th grade ≥ more alcohol and cigarette use
Zhang et al., 2016 [44]	N	X	United States	Secondary school	10,123	13–18	Questionnaire	BT, SD	Diagnostic interview for mental disorder (DSM-IV), parent report behavioral problem	Age, sex, and race/ ethnicity	BTd >2 h vs. 1–2 h ≥ increased odds of substance use (OR $= 2.15$), behavioral disorders (OR $= 1.92$), tobacco smoking (OR $= 1.89$) SDd >2 h vs. 0–2 h ≥ increased odds of behavioral disorders (OR $= 2.01$), tobacco smoking (OR $= 1.41$) SDd ≤ 0 h vs. 0–2 h ≥ increased odds of behavioral disorders (OR $= 1.69$), tobacco smoking (OR $= 1.57$)

Notes. BT = bedtime; RT = rise time; SJL = social jetlag; SD = sleep duration; -d = difference; NA = not applicable; CRSI = Conflict Resolution Styles Inventory; CPIC-Y = Children's Perception of Interparental Conflict Scale for Younger Children; RCPM = Revised Class Play Method; AUD = alcohol use disorders; BDI = Beck Depression Inventory; CBCL = Child Behavior Checklist; DOS = DSM-Oriented Scales; W = wave; T = time; SES = socio-economic statues; SCID = Structured Clinical Interview for DSM-IV; OR = odds ratio; X = cross-sectional study; L = longitudinal study; abs = absolute differences in sleep between weekday and weekend.

Table 5
Characteristics and main finding of included studies regarding weight and metabolic outcomes.

Authors	Meta	Design	Country	Setting	N	Age	Sleep measure	Sleep discrepancy	Outcomes measures	Covariates	Results
Chuang et al., 2015 [73]	Y	X	United States	Children & adolescents	288	11.8 (2.7), 6–18	Questionnaire (parent report)	BT, RT, SD	Measured BMI	Age, gender, race/ ethnicity, marital status and family income	Correlation: BTd ≥ higher zBMI (r = 0.16, p = 0.01) RTd ≥ higher zBMI (r = 0.14, p = 0.03) SDd was not related with zBMI Regression: Female: BTd ≥ higher zBMI (beta = 0.04, p < 0.05) Male: BTd, RTd, SDd were not related with zBMI
Chung & Cheung, 2008 [19]	Y	X	Hong Kong	Secondary school	1629	14.8 (1.7), 12–19	Questionnaire	SD	Self-reported overweight (BMI>25)	NA	SDd was not related with overweight (r = −0.04, p > 0.05)
Chung et al., 2013 [72]	Y	X	Hong Kong	Secondary school	327	14.5 (1.5), 12–19	Questionnaire	BT, SD	Measured BMI (overweight/obese: zBMI>85 percentile)	Socio-demographic and lifestyle variables, naps, insomnia, daytime sleepiness, depression and mean time in bed	BTd: overweight/ obese > normal weight: 75.9 ± 75.0 vs. 53.5 ± 70.7, p < 0.05 Regression: Total sample: BTd ≥ higher zBMI (beta = 0.13, p = 0.04) Age ≥ 15y: BTd ≥ higher zBMI (beta = 0.27, p = 0.007) SDd was not related with overweight/obese
Duran & Haro, 2016 [81]	Y	X	Chile	Primary school	1785	7.7 (1.2), 6–11	Questionnaire (parental report)	SD	Measured BMI (overweight: BMI>85 percentile; obese: BMI>95 percentile)	NA	SDd was not different across normal weight, overweight and obese children
Hall et al., 2015 [88]	N	X	United States	Secondary school	244	15.7 (1.3), 14–19	7d actiwatch	SD	C-reative protein (CRP)	Sex, race, BMI, highest parental education	SDd > 2 h was not associated with high-sensitivity CRP level Regression: SDd >2 h ≥ CRP high risk group (CRP>3 mg/L) (OR = 2.33, 95% CI: [1.01–4.89])
Hayes et al., 2018 [74]	Y	X	Australia	Community	186	14.7 (1.6), 12–17	Questionnaire	BT, SD	Measured BMI, body fat, weight related behaviors (e.g., diet, physical activity, screen time)	BTd: age, gender, sleep duration SDd: age, gender	BTd ≥ higher zBMI (beta = 0.06, SE = 0.03, p = 0.042) SDd was not related with zBMI (beta = −0.005, SE = 0.006, p = 0.434)
Ievers-Landis et al., 2016 [75]	Y	X	United States	Clinic	315	14.5 (1.4), 13–18	Questionnaire (parent report)	BT, RT, SD	Measured BMI	NA	BTd, RTd, SDd were not related with zBMI
Kim et al., 2012 [86]	Y	X	Korea	Primary school	936	10.9 (0.3), 10–11	Questionnaire (parent report)	SD	Measured BMI (overweight: BMI>85 percentile)	Age, sex, eating breakfast, screen time and parental obesity	SDd was longer in non-over-weight than over-weight children (p = 0.029) Regression: SDd ≥ lower risk of being overweight (OR = 0.67, 95% CI: [0.53–0.85]) Interaction between SDd and weekday sleep duration was significant (p = 0.024)

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Table 5 (*continued*)

Authors	Meta	Design	Country	Setting	N	Age	Sleep measure	Sleep discrepancy	Outcomes measures	Covariates	Results
Kuula et al., 2016 [87]	N	L (4yr)	Finland	Primary school	105	8, 12	7-8d actiwatch	SD	Lipid profiles: TC, HDL-C, LDL-C, TGs	Age, BMI, physical activity, pubertal development, socioeconomic status	At 12y: Female: SDd ≥ higher TGs (beta = 0.24, p = 0.02), but not TC, HDL-C, LDL-C Male: SDd was not related with lipid profiles At 8y: SDd was not related with lipid profiles in both genders
Lee et al., 2016 [57]	Y	X	Korea	Secondary school	3785	15.3 (1.5), 11–18	Questionnaire	SD	Reported BMI	Age, BDI, economic status, academic performance, time spent at private tutoring institutes	Partial correlation controlling for age and gender: SDd ≥ lower BMI (r = −0.034, p = 0.036) Regression: Female: SDd ≥ lower BMI (beta = −0.057, p = 0.038) Male: SDd was not related with BMI (beta = -0.021, p = 0.343)
Lin et al., 2018 [58]	N	L (6y)	Taiwan	Secondary school	1747	7th to 12th grade	Questionnaire	SD	Reported BMI	Time, gender, parental education level, BMI, academic stress, mood, physical activity, substance use, commuting	Underweight ≥ greater SDd (B = 2.07, p < 0.05) Overweight ≥ smaller SDd (B = −6.15, p < 0.05) Obesity ≥ smaller SDd (B = −9.20, p < 0.01)
Lytle et al., 2011 [76]	Y	X	United States	Secondary school	723	14.7 (1.8)	Questionnaire	BT, RT, SD	Measured BMIz, body fat percentage, overweight	Race, parent education, lunch status, pubertal status, depression, energy intake and expenditure	BTd, RTd, SDd were not related with BMI z scores RTd ≥ higher risk of being overweight in 5th – 8th grade males Lower percent body fat and risk of being overweight in 9th –12th grade females SDd ≥ higher percent body fat and risk of being overweight in 9th –12th grade females
Malone et al., 2016 [81]	N	X	United States	Secondary school	69	15.5 (0.7), 14–17	7d actiwatch & sleep diary	SJL_{abs}	Measured BMI Waist-to-height ratio	Gender, eating habits, physical activity, weekday sleep duration, naps	SJL ≥ higher zBMI (beta = 0.33, 95% CI: [0.09–0.57], p < 0.01) higher waist-to-height ratio (beta = 0.02, 95% CI: [0.01 −0.04], p < 0.05)
Paiva et al., 2015 [61]	Y	X	Portugal	Secondary school	3476	14.9, 12.5 −19	Questionnaire	SD	Reported BMI	NA	BMI: SDd >3 h vs. ≤3 h: 21.24 ± 3.57 vs. 20.79 ± 3.39, F = 7.61, p = 0.006
Pallesen et al., 2011 [34]	Y	X	Norway	Secondary school	1285	16–19	Questionnaire	SD	Reported BMI	NA	SDd >2 h was not related with BMI
Quan et al., 2018 [83]	Y	L (5y)	United States	Primary & secondary school	327	13.3 (1.7)	Questionnaire (parent-report in first cycle, self-report in second cycle), single night home PSG	SD	Measured BMI, blood pressure	Age, sleep duration, sleep apnea, caffeine consumption	Unadjusted correlation: Parent reported SDd was related with higher systolic BP (r = 0.14, p < 0.05) Child reported SDd was not related with BP Parent or child reported SDd was not related with BMI Partial correlation: SDd was not related with BMI or BP

Schubert & Randler, 2008 [77]	Y	X	Germany	College/University	352	23.2 (2.7),17–42	Questionnaire	RT, SD	BMI	NA	RTd was not related with BMI ($r = 0.063$, $p = 0.281$) SDd was not related with BMI ($r = 0.013$, $p = 0.826$) RTd, SDd were not related with dietary habits
Skidmore et al., 2013 [82]	N	X	New Zealand	Secondary school	685	15.8 (0.9)	Questionnaire	SD	Measured BMI, waist circumference and other body composition indices	NA	SDd was not related with any body composition variable
Stone et al., 2012 [84]	Y	X	Canada	Primary school	856	11 (0.6), 6–12	Questionnaire (parental report)	SD	Measured BMI (overweight/obese: age, gender specified cutoff)	NA	Overweight/obese% ($p < 0.01$): SD weekday <9 h, weekend <9 h: 59.1% SD weekday <9 h, weekend >9 h: 29.0% SD weekday 9–10 h, weekend 9–10 h: 23.6% SD weekday ≥ 10 h, weekend ≥ 10 h: 23.3%
Stoner et al., 2018 [78]	N	X	New Zealand	Primary school	341	9.6, 8–10	Questionnaire (parent report)	SJL_{abs}	Measured adiposity: body fat, fat mass, fat mass index, waist-to-hip ratio (WHR), BMI	School, ethnicity, sex, age	Regression: SJL ≥ higher adiposity indicators (body fat: beta = 2.93, $p = 0.024$; fat mass: beta = 1.73, $p = 0.033$; fat mass index: beta = 0.76, $p = 0.018$; BMI: beta = 0.89, $p = 0.010$; WHR: beta = 0.01, $p = 0.012$).
Von Schnurbein et al., 2018 [80]	N	X	Germany	Clinic	191	16.5 (1.8), 12–21	Questionnaire	SJL_{abs}, SD_{abs}	Measured BMI, HbA1c, insulin requirements	Sleep quality, migration background, gender, type of therapy, diabetes duration, compliance	SJL and SDd was not related with HbA1c SJL ≥ higher insulin requirement in multivariate analysis (beta = 0.04, $p = 0.03$) SDd ≥ higher insulin requirement in only in univariate analysis
Wing et al., 2009 [13]	Y	X	Hong Kong	Primary school	5159	9.3 (1.8), 5–15	Questionnaire (parent report)	SD	Reported BMI (overweight/obese: zBMI>85 percentile)	Age, gender, watching TV ≥ 2 h, time on homework ≥2.5 h, parental education and eating 1 h before going to bed	SD: weekday <8 h, weekend <8 h (vs. weekday <8 h, weekend >8 h) ≥higher risk of overweight/obesity (OR = 2.59, 95% CI: [1.22–5.48]) SD: weekday <9 h, weekend <9 h (vs. weekday <9 h, weekend >9 h) ≥higher risk of overweight/obesity (OR = 1.28, 95% CI: [0.99–1.64])
Wong et al., 2013 [36]	Y	L (3 sems)	Hong Kong & Macau	College/University	930	21.7 (2.2), 18–25	Questionnaire	SD	Reported BMI	NA	Time 1: SDd was not related with BMI
Zhang et al., 2015 [85]	Y	X	China	Primary school	3068	9.3 (1.6), 7–14	Questionnaire (parent report)	SD	Reported BMI (the Group of China Obesity Force cutoff)	Sex, age, suffering illness in the previous 12 mo	Sleep compensation: weekend divergence (SDd/weekday sleep duration *100%) ≥10% Noncompensated group ≥ higher risk of overweight/obesity (OR = 1.197, 95% CI: [1.00–1.49])

Notes. BT = bedtime; RT = rise time; SJL = social jetlag; SD = sleep duration; -d = difference; NA = not applicable; (z)BMI = body mass index (z score); PSG = polysomnography; TC = total cholesterol; HDL-C = high-density lipoprotein cholesterol; LDL-C = low-density lipoprotein cholesterol; TGs = triglycerides; OR = odds ratio; CI = confidence interval; X = cross-sectional study; L = longitudinal study; abs = absolute differences in sleep between weekday and weekend.

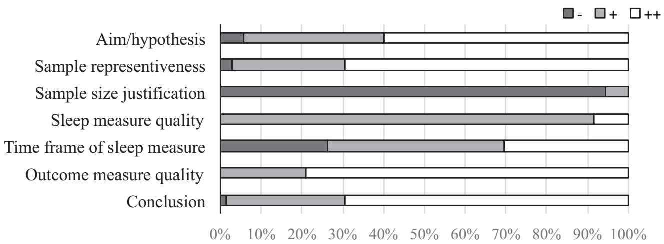

Fig. 2. Summary of the quality assessment of the included studies. Aim/hypothesis: whether there were aims/hypotheses specific to week-to-weekend sleep differences; "++" indicates specific aims/hypotheses related to weekday-to-weekend sleep differences; "+" indicates aims/hypotheses related to any sleep-wake patterns; "-" indicates no aim/hypothesis specific to sleep. Sample representativeness: representativeness of samples for the intended study population and for conclusions drawn, with "++", "+", and "-" indicating "good", "fair", and "poor". Sample size justification: whether sample size was justified; "++" indicates justified, "+" indicates justified based on outcomes other than weekday-weekend differences, "-" indicates unjustified. Sleep measure quality: "++" indicates any objective measure (e.g., actigraphy) was included, "+" indicates that sleep was measured by subjective report only. The timeframe of sleep measure: the number of continuous days covered; "++" indicates >14 d, "+" indicates 7–14 d (using questionnaire without explicitly providing the information about the timeframe of the measure was coded as "+"), and "-" indicates <7 d. Outcome measure quality: "++" indicates well validated, "+" indicates not well validated. Inferences and conclusions: quality of inferences and conclusions drawn, with "++", "+", and "-" indicating "good", "fair", and "poor".

Mood-related disturbances (n = 26)

Differences in bedtime and rise time. There were six studies that reported the findings on the association between BTd and depressive symptoms [21,22,43–46]. The pooled results from five studies suggested that BTd was not significantly correlated with depressive symptoms ($r = 0.01$, $p = 0.664$; $I^2 = 86.32\%$; Fig. 4A). There was one study, which was not included in this meta-analysis due to a lack of sufficient data to derive a correlation coefficient, reporting that greater BTd was associated with a higher level of depressive symptoms, but this association became insignificant after controlling for insomnia, snoring and daytime sleepiness [43]. When the analysis was limited to those conducted in the secondary school students, the pooled results suggested that larger BTd was correlated with increased depressive symptoms ($r = 0.06$, $p < 0.001$; Table S3). A possible gender difference was reported in one study, in which a significant correlation between BTd and depressive symptoms was found in only female but not male secondary school students [22]. Moreover, over two hours of BTd were found to be associated with increased self-harming behaviors and higher suicidality in the secondary school students [44,47]. Two studies, which have taken potential confounding factors (e.g., insomnia) into account, showed mixed results on the association between RTd and depressive symptoms. One study found that greater RTd was related to more depressive symptoms [43], whilst the other study found insignificant association [46].

One study reported that unaffected child and adolescent offspring of bipolar patients had larger RTd, but not BTd. However, this association was no longer significant after controlling for the current mood state [48]. Moreover, two studies reported no association of BTd and RTd with anxiety symptoms in the secondary school students [44,49].

Social jetlag. There were three studies that tested the association between SJL and depressive symptoms particularly in the youths. Due to the high heterogeneity in the defined outcomes (e.g., depressive symptoms vs. seasonal affective disorder) across these three studies, a meta-analysis was not conducted. De Souza and Hidalgo reported no association between SJL and depressive symptoms in the youths [50]. In contrast, Haynie et al. reported that SJL was associated with depressive mood in the secondary school students in a cross-sectional survey study [51]. Gender differences in the relationship between SJL and depressive mood have been reported, with a significant association found in only female but not male adolescents [52].

SJL was also not found to be a significant risk factor for a constellation of symptoms related to severe mental illnesses, including hallucination, paranoia, anxiety, depression and (hypo) mania, in a study based on the university student population [53]. In addition, SJL was not found to be related to life satisfaction and positive mood in a sample of college students [54]. In a prospective study conducted in the secondary school students, SJL reported at baseline was not found to be a significant predictor of emotional wellbeing at one-year follow-up [33]. In another cross-sectional survey, Díaz-Morales found that secondary school students with different anxiety levels had comparable SJL [55].

Difference in sleep duration. There were 10 studies that investigated the association between SDd and depressive symptoms in the youths [21,22,34,36,43,44,46,56–58]. Among these 10 studies, two were not included in the meta-analysis due to their different study design (longitudinal vs. cross-sectional), one was excluded from the analysis due to a lack of sufficient data to derive a correlation coefficient. The data from seven studies were extracted for analysis. The pooled results suggested that SDd was positively correlated with depressive symptoms ($r = 0.06$, $p < 0.001$; $I^2 = 63.11\%$; Fig. 4B), and this association remained significant in the sensitivity analyses (Table S4). One longitudinal and one cross-sectional study, which were not included in this meta-analysis, showed that greater SDd was associated with more depressive symptoms [43,58], whilst another longitudinal study found an insignificant association between SDd and depression [56]. Gender differences in the relationship between SDd and depressive symptoms have been reported. In particular, larger SDd was related to more depressive symptoms in boys, whilst larger SDd was related to less depressive symptoms in girls [57]. Moreover, there was consistent evidence supporting that larger SDd was associated with an increased risk for suicidal ideations and attempts in the youths [43,44,59].

Three studies investigated the association of SDd with anxiety symptoms, but meta-analysis was not conducted due to different study designs. One cross-sectional study and one longitudinal study found no relationship between SDd and anxiety symptoms [34,36], whilst one study reported that shorter SDd (i.e., less than 0 h) was related to increased anxiety symptoms [44].

Among the youths, smaller SDd was found to be associated with better general mental health [60], whilst larger SDd was found to be associated with higher perceived stress level [19], lower self-esteem and poorer quality of life [36,61].

Behavioral problems and substance use (n = 21)

Differences in bedtime and rise time. Due to the heterogeneity in the outcome measures, a meta-analysis was not conducted to examine the association of BTd and RTd with behavioral problems. Four studies conducted among the youths reported that BTd was associated with an increased risk for behavioral problems, such as risk-taking behaviors, and aggressive and antisocial behaviors [21,44,46,49]. One study found that secondary school students with larger BTd and RTd were more likely to have psychosocial problems related to bullying [62]. In contrast, one study conducted in eight-year-old children found no association of BTd and RTd with behavioral problems as rated by parents [63].

The associations of BTd and RTd with the use of substances, including cigarette, alcohol, and drugs (e.g., marijuana), have been investigated mostly in the youths [21,25,44–46,64,65]. The pooled results from six cross-sectional studies suggested that BTd was associated with a higher risk of substance use ($r = 0.25$,

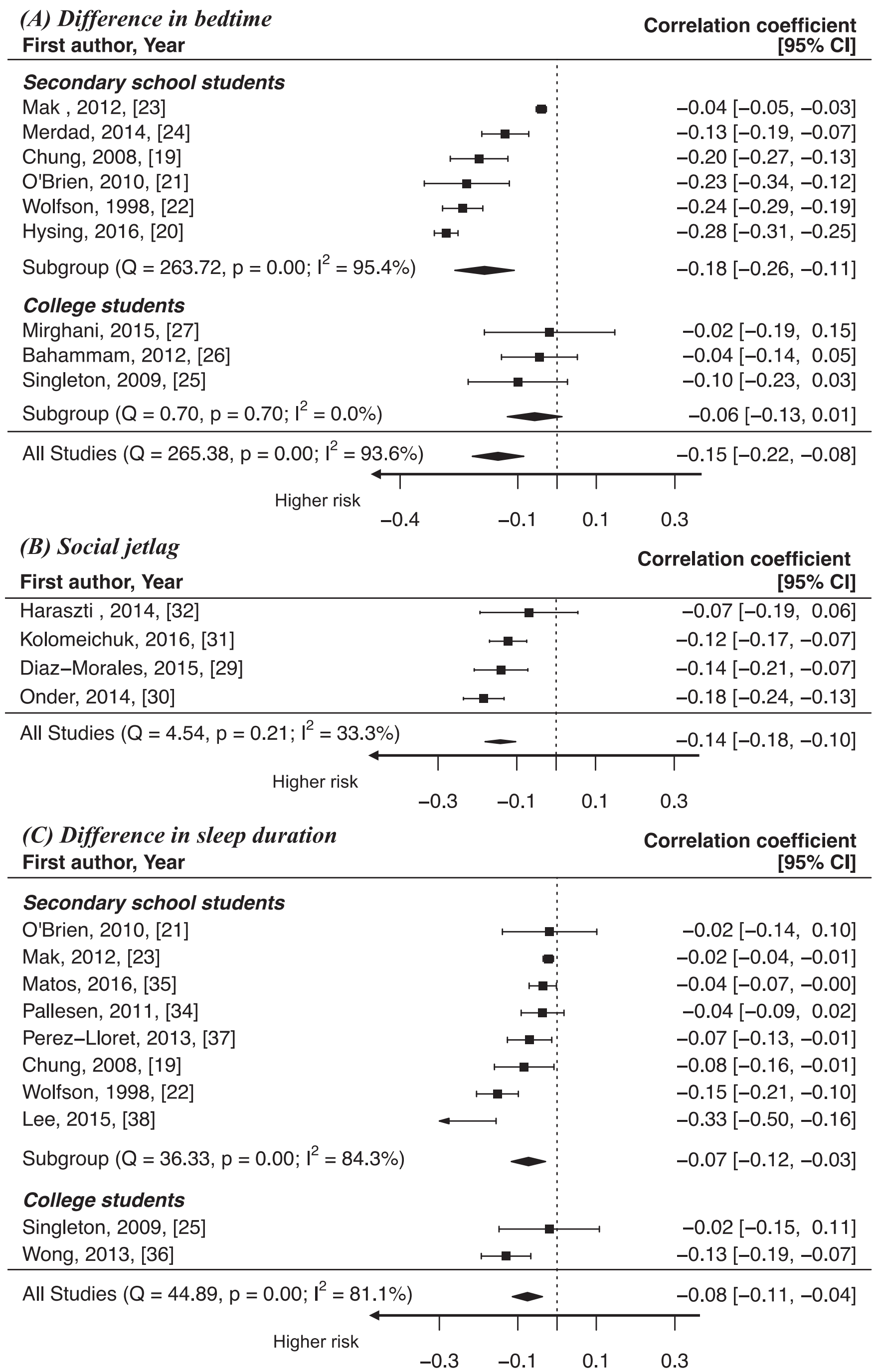

Fig. 3. Forest plot showing the association between weekday-to-weekend sleep differences and academic performance. (A) The effects of weekday-to-weekend difference in bedtime. Larger difference in bedtime was correlated with poorer academic performance ($r = -0.15$, 95% CI: [−0.22, −0.08]). Overall heterogeneity was high. (B) The effects of weekday-to-weekend difference in mid-point of sleep (social jetlag). Larger social jetlag was correlated with poorer academic performance ($r = -0.14$, 95% CI: [−0.18, −0.10]). Overall heterogeneity was low. (C) The effects of weekday-to-weekend difference in sleep duration. Larger difference in sleep duration was correlated with poorer academic performance ($r = -0.08$, 95% CI: [−0.11, −0.04]). Overall heterogeneity was high.

$p < 0.001$; $I^2 = 89.01\%$), including tobacco ($r = 0.25$, $p = 0.004$), alcohol ($r = 0.27$, $p < 0.001$) and drugs ($r = 0.21$, $p < 0.001$; Fig. 5A). From a longitudinal perspective, one study found that BTd only predicted alcohol use, but not cigarette or marijuana use, whilst substance use could not predict BTd in the youths [66]. Another study reported that RTd but not BTd was predictive of later marijuana use, and neither BTd nor RTd could predict alcohol use at one-year follow up [65]. A lack of long-term effects of BTd on substance use was also reported [49]. One study conducted in the school-age children found no direct association of BTd and RTd with substance use, but the effects might be mediated through executive function [67].

Social jetlag. A meta-analysis was not conducted on the effect of SJL due to the limited studies available, which were based on various outcomes including aggression and behavioral problems ($n = 2$) and substance use ($n = 2$). There was some evidence suggesting that SJL was related to increased aggression and behavioral

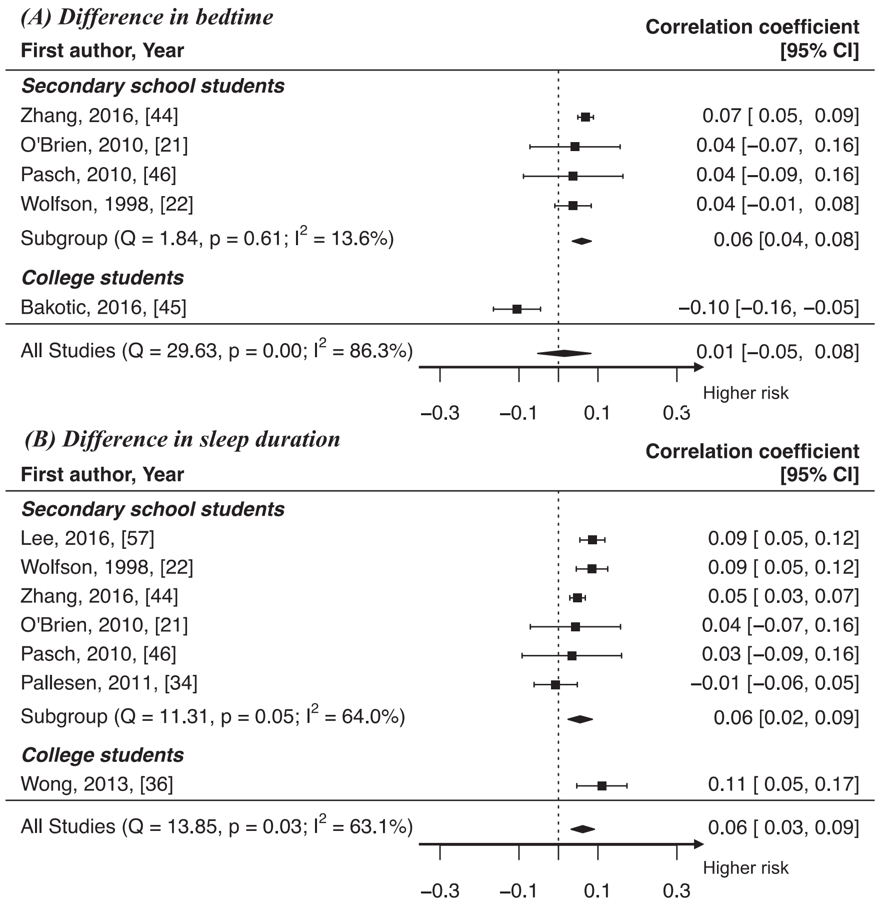

Fig. 4. Forest plot showing the associations between weekday-to-weekend sleep differences and depressive symptoms. (A) The effects of weekday-to-weekend difference in bedtime. Larger difference in bedtime was not correlated with more depressive symptoms in the overall sample ($r = 0.01$, 95% CI: [−0.05, 0.08]). Overall heterogeneity was high. (B) The effects of weekday-to-weekend difference in sleep duration. Larger difference in sleep duration was correlated with more depressive symptoms in the overall sample ($r = 0.06$, 95% CI: [0.03, 0.09]). Overall heterogeneity was low.

problems in the youths. Randler and Vollmer found that greater SJL was associated with increased physical and verbal aggression, but not anger or hostility based on the self-report measures in a sample of college students [68]. Among the secondary school students, SJL was found to be associated with concurrent conduct problems and defiance attitude, but was not predictive of conduct problems one year later [33]. One recent longitudinal study showed a bidirectional association between SJL and alcohol use in the secondary school students [51]. However, in the college students, SJL was found to be predicted by a previous history of substance use (i.e., alcohol and marijuana), but could not predict substance use or academic adjustments in the following year [69].

Difference in sleep duration. There were insufficient studies ($n = 2$) for the meta-analysis on the relationship between SDd and aggression and behavioral problems. Lemola and colleagues found that SDd was a moderator linking the environmental risk factors (e.g., interparental conflict) to aggression in the youths [70]. In addition, SDd was found to be related to paternal-rated, but not maternal-rated, behavioral problems in 8-y-old children [63].

The effect of SDd on substance use was also reported in six cross-sectional studies conducted in the youths [19,21,25,44,46,71]. The pooled results from these cross-sectional studies and the baseline data of a longitudinal study suggested that SDd was not associated with substance use in the secondary school students and college students ($r = 0.05$, $p = 0.069$; $I^2 = 86.8\%$; Fig. 5B). Specifically, no significant association was found between SDd and tobacco use ($r = 0.03$, $p = 0.239$) or alcohol use ($r = 0.07$, $p = 0.128$) in the subgroup analyses. In addition, three longitudinal studies investigated the association between SDd and adolescent substance use [56,58,66]. Pasch and colleagues reported that SDd at 2-y follow-up was predicted by baseline alcohol and marijuana use, but not vice versa [66]. However, Hasler and colleagues reported that greater SDd at baseline was predictive of increased alcohol use at 5-y follow up [56]. Another study found that SDd overtime was only related to tobacco smoking, but not alcohol consumption and betel nut chewing [58].

Weight and metabolic outcomes (n = 24)

Differences in bedtime and rise time. There was some evidence showing the negative impacts of weekday-to-weekend difference in sleep timing on the risk of overweight/obese in children and youths [72–76]. The pooled results from five studies showed a significant positive correlation between BTd and the risk of being overweight/obese ($r = 0.10$, $p < 0.001$; $I^2 = 35.77\%$; Fig. 6A). In addition, Chung and colleagues found that the predictive effect of BTd on BMI was more prominent among the youths over 15 y old [72]. Another study indicated that the association remained significant only among females after controlling for potential socio-demographic confounders [73].

The pooled results from the three studies conducted in the children and youths showed an insignificant correlation between RTd and BMI score ($r = 0.06$, $p = 0.122$; $I^2 = 46.05\%$; Fig. 6B) [73,76,77]. There was evidence to suggest the moderating effects of

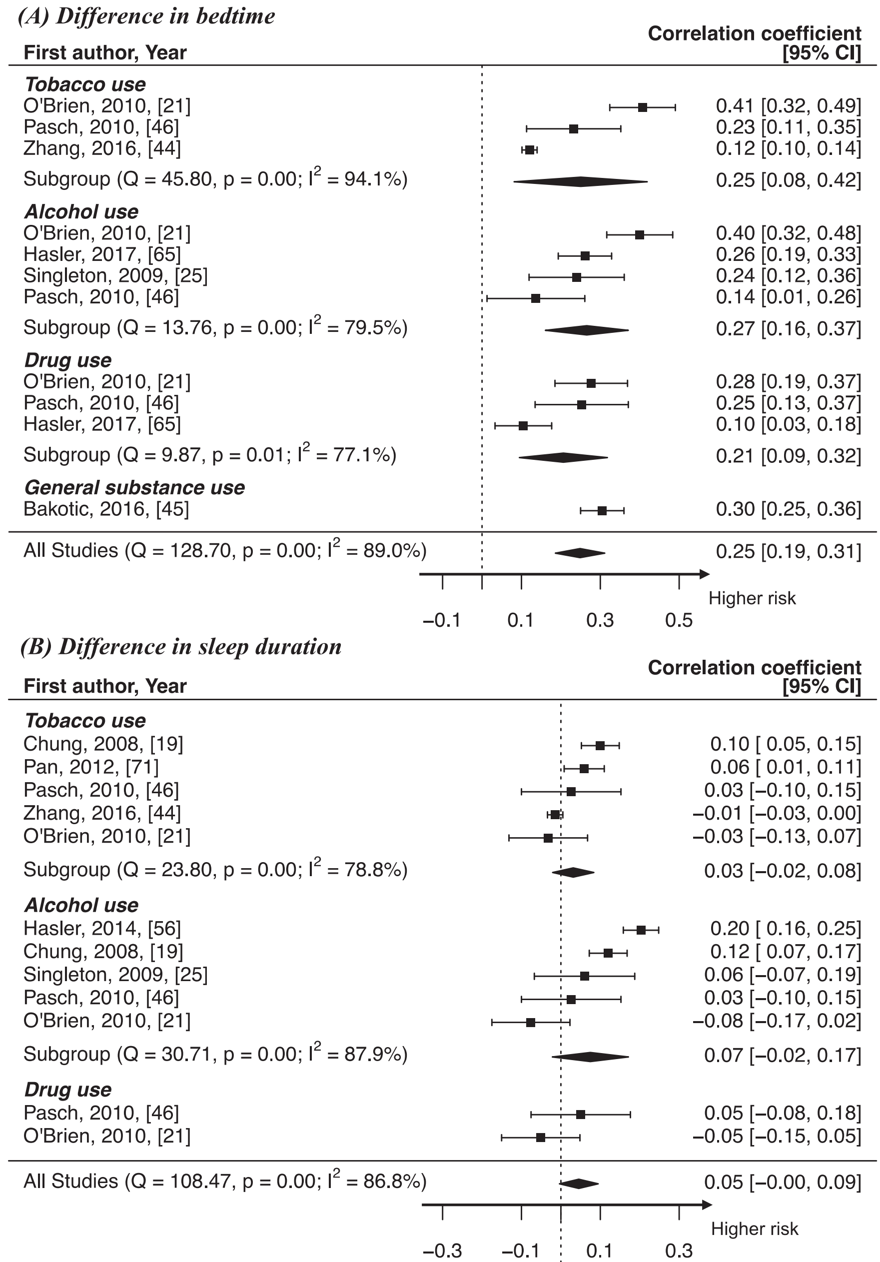

Fig. 5. Forest plot showing the associations between weekday-to-weekend sleep differences and substance use. (A) The effects of weekday-to-weekend difference in bedtime. Larger difference in bedtime was correlated with increased risk of substance use ($r = 0.25$, 95% CI: [0.19, 0.31]). Overall heterogeneity was high. (B) The effects of weekday-to-weekend difference in sleep duration. Larger difference in sleep duration was not correlated with the risk of substance use ($r = 0.05$, 95% CI: [>−0.01, 0.09]). Overall heterogeneity was high.

gender and age, as younger male youths with greater RTd were found to have a higher risk of being overweight, whilst greater RTd was associated with a lower risk of being overweight in older, female youths [76].

Social jetlag. A meta-analysis was not conducted on the effect of SJL due to the limited and heterogeneous studies available ($n = 3$). Greater SJL was found to be associated with increased adiposity (e.g., BMI, waist-to-height ratio and body fat) among children and youths [78,79]. One study further suggested that the effect of SJL on BMI was independent of weekday sleep duration [79]. Only one study has investigated the association between SJL and glycemic regulation in the youths with type 1 diabetes, and found that SJL was related to higher insulin requirement, an indirect marker of insulin resistance, but not to HbA1c [80].

Difference in sleep duration. There were 19 studies that investigated the associations between SDd and weight status in children and youths [13,19,34,36,57,58,61,72–77,81–86]. The pooled results from 17 studies suggested that greater SDd was associated with a lower risk of being overweight/obese with high heterogeneity ($r = -0.03$, $p = 0.037$; $I^2 = 78.17\%$; Table S5). Further analyses showed that the association between SDd and the risk of being overweight/obese was more prominent particularly in Asian children ($r = -0.12$, $p < 0.001$) and Asian youths ($r = -0.03$, $p = 0.018$; Fig. 6B). One study, which was not included in this meta-analysis

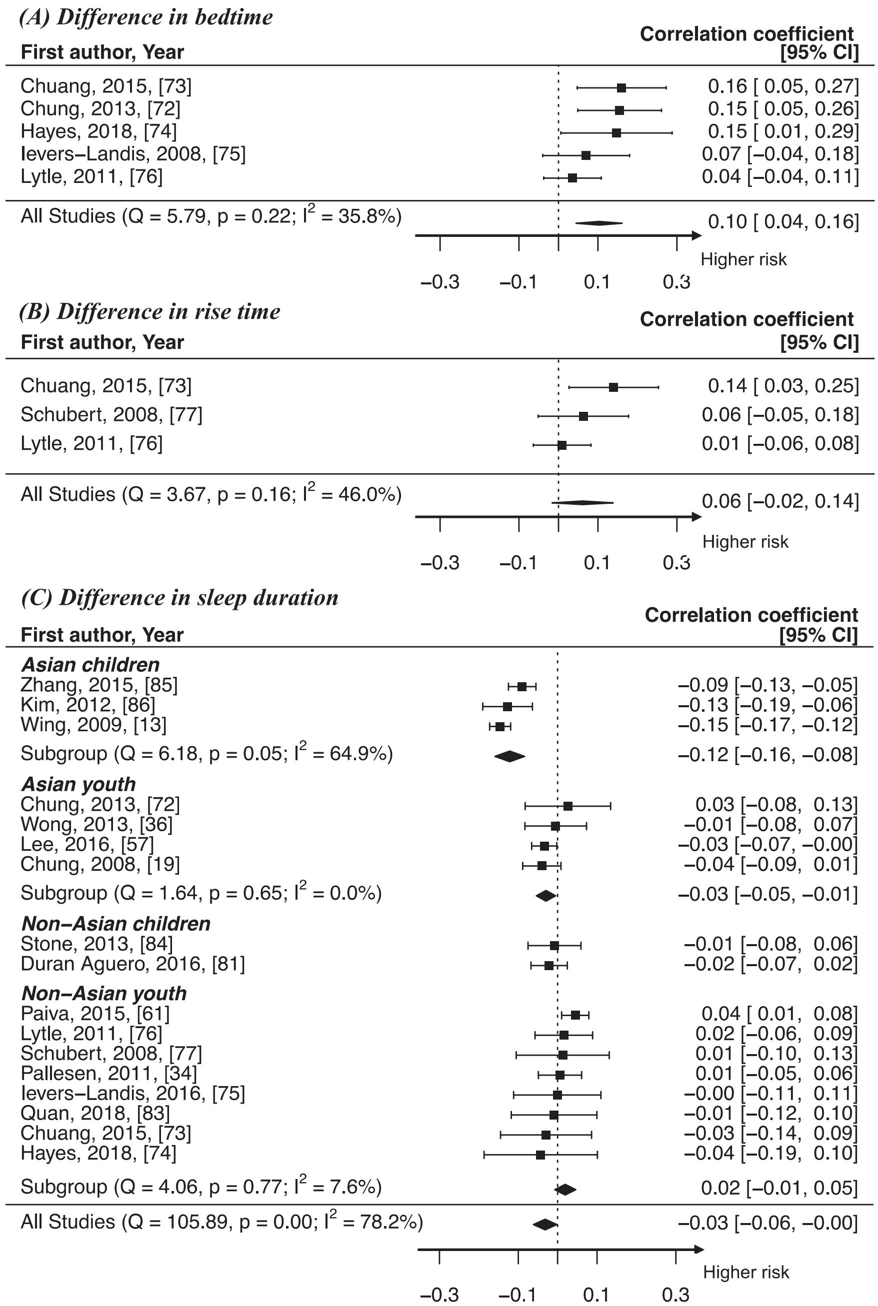

Fig. 6. Forest plot showing the association between weekday-to-weekend sleep differences and body mass index (BMI). (A) The effects of weekday-to-weekend difference in bedtime. Larger difference in bedtime was correlated with increased risk of overweight/obesity (r = 0.10, 95% CI: [0.04, 0.16]). Overall heterogeneity was low. (B) The effects of weekday-to-weekend difference in rise time. Larger difference in rise time was not correlated with the risk of overweight/obesity (r = 0.06, 95% CI: [−0.02, 0.14]). Overall heterogeneity was low. (C) The effects of weekday-to-weekend difference in sleep duration. Larger difference in sleep duration was correlated with decreased risk of overweight/obesity (r = −0.03, 95% CI: [−0.06, >−0.01]). Overall heterogeneity was high.

due to insufficient data to derive a correlation coefficient, found no association between SDd and any body composition variables in the youths [82]. A longitudinal study, which was not included in this meta-analysis, found that underweight adolescents tended to have greater SDd, whilst overweight/obese adolescents tended to have smaller SDd throughout the follow-up period [58]. Gender differences in the relationship between SDd and BMI were suggested by some studies. Lee and colleagues reported that larger SDd was related to lower BMI among only female but not male children and youths [57]. Another study found that greater SDd was associated with higher body fat percentage and the risk of being overweight in older female youths but not male or younger youths [76]. In addition, the effect of SDd on weight gain was found to be larger among children with shorter weekday sleep duration [86].

There were four studies that investigated the association of SDd with other metabolic related outcomes, but a meta-analysis was not performed because of their use of different outcome measures. One study found that SDd was not associated with the lipid profile in 8-y-old children, but larger SDd at baseline was predictive of increased triglycerides at 4-y follow up, particularly in girls [87]. Although SDd was not found to be associated with increased C-reactive protein (CRP) in the healthy youths, those with over 2 h of

SDd were more likely to be in the CRP high-risk group (CRP>3 mg/L) [88]. In the youths with type 1 diabetes, SDd was not found to be related to HbA1c but was reported to be associated with higher insulin requirements. However, this association was no longer significant after controlling for potential confounders (e.g., gender and diabetes duration) [80]. One study reported no significant relationship between SDd and blood pressure [83].

Discussion

The main objectives of the current review were to examine the associations of weekday-to-weekend sleep differences with academic performance and health-related outcomes in school-age children and youths. Weekday-to-weekend differences in bedtime and sleep duration were found to be the most commonly studied sleep parameters in this population, whilst fewer studies were focused on the differences in rise time and mid-point of sleep. There was evidence to support the associations of weekday-to-weekend sleep differences with academic performance, depressive symptoms, substance use and the risk for overweight/obesity. However, the relationship between weekday-to-weekend sleep differences and specific cognitive abilities, anxiety symptoms and other metabolic related outcomes, such as the regulation of glucose and lipid metabolism as well as blood pressure, remained inconclusive.

In general, a complex relationship between weekday-to-weekend sleep differences and daytime functioning was observed in the young population. First, there was an age-related effect of weekday-to-weekend sleep differences, which were found to increase with increasing age during adolescence [6,89]. There was stronger evidence on the associations of weekday-to-weekend sleep differences with academic performance, depressive symptoms, and body weight among secondary school students as compared to college students. Second, the distinct effects of weekday-to-weekend differences in sleep timing and sleep duration were observed. In particular, weekend sleep delay (i.e., weekday-to-weekend difference in sleep timing) had a stronger adverse effect on academic performance, substance use and body weight, when compared with weekend catch-up sleep (i.e., weekday-to-weekend difference in sleep duration). These differences may be related to different processes underlying weekday-to-weekend differences in sleep timing and duration. Whilst sleep timing differences may reflect a circadian-related process (e.g., circadian misalignment), the difference in sleep duration between weekdays and weekends may be a manifestation of the homeostatic process, e.g., large differences in sleep duration may reflect the attempt of sleep compensation in response to sleep debt accumulated during weekdays. Third, the effects of weekday-to-weekend sleep differences varied for different health-related outcomes. For example, longer weekend catch-up sleep was associated with more depressive symptoms, but interestingly showed a beneficial effect on body weight.

A significant association of small to medium magnitude was found between weekday-to-weekend sleep differences and academic performance. In particular, larger difference in sleep timing was correlated with poorer academic performance, especially in the secondary school students, whilst the effect size of this association decreased in the older youths (i.e., college students). Greater weekend bedtime delay among the secondary school students may be due to the discrepancy between fixed, early school start time during weekdays and later circadian phase in the adolescents [90]. The reduced effect of the difference in sleep timing on academic performance in the college students may be potentially explained by the fact that they have more flexibilities in choosing and scheduling their classes to match their diurnal preferences, as compared to those adolescents in the secondary schools. In addition, larger difference in sleep duration showed a modest correlation with poorer academic performance regardless of the academic context (secondary schools vs. colleges). A previous study showed that students with larger SDd reported feeling more pressure from school work and a higher degree of disliking school, which might be the potential reason or mediator linking SDd to academic performance [35].

Although academic performance was found to be associated with weekday-to-weekend sleep differences, it remained inconclusive whether these sleep differences affected specific cognitive abilities. This observation was similar to that of a previous review on day-to-day sleep variability in children and adolescents [4]. It may be possible that cognitive abilities are differentially sensitive to the effects of the weekday-to-weekend differences in sleep timing and sleep duration. For example, poorer inductive reasoning was found among individuals with larger sleep timing difference (e.g., SJL) [29], and sustained attention was found to be the most vulnerable to the effects of sleep loss [15]. Nonetheless, the existing studies on the association between weekday-weekend sleep differences and cognitive abilities were limited, with a high heterogeneity due to the use of different outcome measures. There is a need for further research to explore which cognitive domains may be more vulnerable to the effect of weekday-to-weekend sleep differences. Meanwhile, as cognitive functioning is related to various factors (e.g., gender, pubertal development) [12], and is also sensitive to other sleep characteristics (e.g., insufficient sleep and poor sleep quality) [1], potential confounding factors should also be considered in future studies.

There was some evidence showing the relationship between weekday-to-weekend sleep differences and depressive mood in youths. However, there were insufficient data to show a clear association of weekday-to-weekend sleep differences with anxiety symptoms and other mood-related disturbances (e.g., manic/hypomanic episodes). The pooled results indicated a significant association of small magnitude between weekday-to-weekend sleep differences and depressive symptoms, particularly in the secondary school students. This finding suggested their vulnerability to the effects of circadian misalignment. However, current evidence was not sufficient to conclude an association between weekday-to-weekend sleep differences and depressive mood in the older youths (e.g., college students) due to the limited studies conducted in this age group. It is also possible that college students tend to have more flexible class/activity schedules than secondary school students, which might give rise to increasing day-to-day sleep variability but reduced weekday-to-weekend sleep differences. Our results supplemented previous reviews, suggesting that weekday-to-weekend sleep differences might have a close association with mental well-being in the young people [4], whereas the effects of day-to-day sleep variability on mood symptoms may be more prominent in the adults [11]. Moreover, there was consistent evidence, albeit limited, to show that larger sleep differences in both timing and duration were associated with an increased risk of suicidality in the youths (particularly secondary school students). Previous research has consistently suggested sleep disturbances (e.g., insomnia, nightmares) as a risk factor for suicidality in both the general and clinical populations [91,92]. Our findings further highlighted that weekday-to-weekend sleep differences might be another important sleep aspect that should be taken into consideration in the sleep and suicide research, as well as the clinical management and prevention of suicide risk in the young population. Given that the risk for suicidality may be linked to multiple psychosocial and cognitive factors, such as high impulsivity, risky behavioral tendency, and impaired decision-making as well as depressive mood, there is a need for further research to explore different psychopathological pathways linking weekday-to-weekend sleep differences to suicidality.

Weekday-to-weekend differences, especially in bedtime, showed a significant association of medium magnitude with an increased risk for substance use in youths. Differential associations of weekday-to-weekend differences in sleep timing and sleep duration with substance use were found. In this regard, a previous study has found that compared with repeated chronic sleep restriction and recovery, greater shifts in circadian rhythm were linked to specific impairments of the reward-related processes [42]. It is possible that BTd and RTd may compromise executive functions, thereby increasing the risk of substance use [67]. Nonetheless, the existing findings from the longitudinal studies on the directions of the relationship between weekday-to-weekend sleep differences and substance use remained controversial. There was evidence to show a relationship between weekday-to-weekend sleep differences and behavioral problems in youths, whereas such associations in school-age children were less clear, with some evidence mostly from the cross-sectional studies. Moreover, the only longitudinal study was conducted among preschoolers, showing that larger SDd was associated with more behavioral problems at 1-mo but not at 3-mo follow-up [93]. Future longitudinal and interventional studies are needed to further delineate the causality between weekday-to-weekend sleep differences and substance use as well as behavioral problems in the young population.

A distinct pattern of association between weekday-to-weekend sleep differences and weight gain was found. Specifically, larger difference in sleep timing (i.e., bedtime) was related to an increased risk for overweight/obesity in the overall samples with a small effect size. However, larger weekend catch-up sleep was associated with a lower risk for overweight/obesity especially in Asian children and youths with a small effect size. Previous research has shown a link between insufficient sleep and increased abdominal adiposity and decreased insulin sensitivity in children and adolescents [2]. Meanwhile, greater weekend sleep delay has been reported to be associated with more dietary intake, which might increase the risk of being overweight/obese. In contrast, greater weekend catch-up sleep was not found to be associated with eating behaviors [75]. Taken together, weekend sleep compensation might potentially serve a protective role against childhood overweight/obesity, possibly by ameliorating the detrimental effects of sleep deprivation during weekdays. The findings on the stronger effect of weekend sleep compensation on ameliorating the risk for overweight/obesity in young Asian populations might be related to the fact that the students in Asian countries tend to go to bed later and have shorter sleep duration during weekdays as compared to their non-Asian counterparts [94]. However, it remained inconclusive how weekday-to-weekend sleep differences might affect metabolic-related outcomes in children and adolescents, as there were limited studies with mixed results on the associations of the difference in sleep timing with metabolic functions (e.g., lipid and glucose metabolism). Moreover, our current findings regarding the association between weekday-to-weekend sleep differences and metabolic-related outcomes based on the naturalistic observational studies conducted in the young population were in contrast with that of experimental studies conducted in the adult populations, in which weekend catch-up sleep was not found to ameliorate or prevent metabolic dysregulation [16,95]. Further research is warranted to examine the possible metabolic pathways linking weekday-to-weekend sleep differences to overweight/obesity particularly among children and youths.

The findings of the present review should be considered in light of several limitations. First, whilst the results of weekday-to-weekend differences in different sleep parameters (e.g., sleep timing, sleep duration) were summarized and discussed separately, these sleep characteristics were often inter-related and should not be considered as independent sleep factors. For example, previous experimental studies simulating weekend sleep compensation by inducing repeated sleep restriction followed by sleep extension/recovery suggested that delay in bedtime [14], delay in rise time [96], or both [97] could result in delayed circadian phase as measured by dim light melatonin onset (DLMO), regardless of the changes in sleep duration. Therefore, the findings regarding the difference in sleep duration might be related to the joint effects of the changes in both sleep duration and phase shift in one's circadian rhythm. Future studies may need to consider these interrelated sleep factors underlying weekday-to-weekend sleep differences when examining their associations with daytime functioning. Second, most of the identified observational studies adopted a cross-sectional design with the use of subjective measures of sleep-wake pattern. The cross-sectional design precluded a causal inference, and the subjective estimate of sleep-wake pattern might be biased by other factors, such as mood state and personality [98]. Future studies should consider adopting longitudinal or interventional design with the use of objective sleep measures. Third, most of the studies included in the quantitative analyses reported unadjusted results, and the potential confounding factors were not considered, such as gender, pubertal development, and average sleep parameters. For example, several studies have reported gender differences in the relationship between weekday-to-weekend sleep differences and outcome measures, such as mood and body weight [22,52,57]. In addition, weekday-to-weekend sleep differences could be related to other sleep problems, such as insufficient sleep and clinical sleep disorders (e.g., insomnia) [99], which have been shown to be the risk factors for health-related outcomes (e.g., emotional and behavioral problems) [100]. Due to the limited available data, meta-regression was not conducted to test the potential moderators, and whether the effects of weekday-to-weekend sleep differences were independent of these factors remained inconclusive [48,73]. Future studies could consider using more sophisticated study design and statistical modeling to delineate the effects of weekday-to-weekend sleep differences whilst taking into account other sleep, circadian and psychosocial factors. Fourth, most of the existing studies examined the linear association between weekday-to-weekend sleep differences and daytime functioning. The possibility of different patterns of associations (e.g., U-shaped), which might potentially explained some of the mixed findings in the current literature, remained untested. Fifth, the existing studies were heterogeneous in terms of the use of different terms to describe weekday-to-weekend differences. In addition, whilst we operationalized ‘social jetlag’ as ‘weekday-to-weekend difference in mid-point of sleep’ in this review, assuming weekends were the ‘free days’ on which one's sleep schedules were not dictated by other social obligations, this might not necessarily be the case for all the children and youths in the study samples. Sixth, the current review did not consider the holiday effects, which could potentially affect the sleep-wake patterns, especially in school-age children and youths. For instance, previous research has suggested that youths tend to go to bed later but have a longer sleep duration with greater variability during vacations [3].

In summary, the current systematic review indicated that weekday-to-weekend sleep differences were associated with academic performance and some health-related outcomes in school-age children and youths. Although weekday-to-weekend sleep differences could potentially have a negative impact on several aspects of mental and physical health in children and youths, weekend catch-up sleep was found to be associated with a lower risk of overweight/obesity especially for Asian children and youths, possibly due to its effect of ameliorating the negative impact of weekday sleep loss on weight gain. Nonetheless, the findings on the effects of weekday-to-weekend sleep differences should be interpreted with caution, because the observed effects may be as a result of sleep restriction and compensation as well as circadian misalignment. There is a need for further research to clarify to what extent and under what circumstances weekday-to-weekend sleep differences may show differential effects on health and daytime functioning in children and youth. Our results generally suggested the need for enhancing awareness towards the importance of maintaining not only adequate duration of sleep but also regular sleep schedule in the young people. In this regard, school-based sleep education has been previously shown to be effective in improving sleep knowledge in the students [101]. To optimize daytime functioning in children and youths, it may be necessary for parents and clinicians to be attentive to the young people's sleep-wake schedule during weekdays and weekends in relation to other psychosocial and environmental factors that may disturb their sleep pattern. Nonetheless, the existing literature on weekday-to-weekend sleep differences is limited by several methodological constraints. Future research should consider adopting longitudinal and experimental designs, and the use of objective sleep measures to further examine the impacts of weekday-to-weekend sleep differences on mental and physical health in the young population and to gain more insight into the mechanisms underlying their associations.

Practice points

- Children and youths with longer weekend sleep timing delay may be more likely to have poorer academic performance, more depressive symptoms, more substance use and increased risk for being overweight/obese.
- Youths, particularly secondary school students, with longer weekend catch-up sleep, may be more likely to have poorer academic performance and more depressive symptoms.
- The adverse effects of weekday-to-weekend sleep differences are more prominent in the secondary school students as compared to the college students, which might suggest that younger youths are particularly susceptible to the effects of the misalignment between internal circadian phase and societal demands.
- Weekend catch-up sleep may potentially ameliorate the risk of overweight/obesity especially for Asian children and youths who are often chronically sleep deprived during weekdays.
- There is some evidence to suggest that greater weekday-to-weekend differences in both sleep timing and sleep duration are associated with an increased risk for behavioral problems in children and youths, as well as an enhanced risk for suicidality, particularly in the secondary school students.

Research agenda

Given the inconclusive findings and methodological issues of the existing literature, future studies are warranted to:

- Further conceptualize and examine weekday-to-weekend sleep differences whilst considering the conjunctive effects of changes in circadian phase and sleep restriction, as well as the other developmental factors (e.g., puberty)
- Investigate the association between weekday-to-weekend sleep differences and specific cognitive abilities, stress-related responses and anxiety, as well as cardiometabolic risks
- Explore the underlying mechanisms linking weekday-to-weekend sleep differences to academic performance and health-related outcomes, such as structural and functional brain changes, cardiovascular systems and endocrine regulation
- Utilize longitudinal design and objective sleep measures to delineate the causality between weekday-to-weekend sleep differences and health-related outcomes.

Conflicts of interest

The authors do not have any conflicts of interest to disclose.

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Appendix A. Supplementary data

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