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RESEARCH ARTICLE

Daily Variation in Sleep Duration, Affect, and Emotions in Croatian Youth: An Ambulatory Assessment

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Introduction: Sleep habits are related to mood stability and mental health, and adolescence may be an appropriate time to address disturbed sleep patterns because it is a critical period for the onset of psychological problems.
Aims: This study had two aims, namely: to explore associations between objectively measured sleep duration and positive and negative affect, as well as specific positive and negative emotions at the within-person and between-person levels in Croatian adolescents.
Methods: In the present eight-day study, 102 Croatian adolescents with an average age of 15 years reported how they felt once a day, while sleep duration was objectively measured by collecting data from an accelerometer on participants' smartphones.
Results: Multilevel analyses showed that adolescents express more positive affect (Est. = 0.10, $p < .050$) and feel less distracted (Est. = -0.12, $p < .050$) and happier (Est. = 0.11, $p < .050$) on days when they sleep longer, with a multiverse analysis suggesting that these results are moderately robust. In addition, they express higher levels of negative affect, stress and distraction on school days, and boys seem to experience more positive and fewer negative emotions.
Conclusions: A better understanding of daily variations in sleep duration, sleep quality, and affect would promote the development of individualized, particularly smartphone-based, sleep interventions. Such interventions could be a valuable tool for preventing mental health problems in adolescence.

Keywords: adolescence, mental health, sleep duration, ambulatory assessment, passive sensing data

Introduction

Scientists are exploring many ways to improve adolescent well-being (UNICEF, 2021; Solmi et al, 2020). One interesting pattern in adolescent development is related to their sleep and its quality (Gradisar et al., 2011). Adolescence may be a particularly appropriate time to address disturbed sleep patterns, as it is a critical period for the onset of psychological problems, but also an important period for the formation of healthy habits (Scott et al, 2021; Short et al, 2020). Numerous studies have clearly demonstrated that, on average, adolescents do not sleep optimally and that their sleep patterns do not ensure adequate levels of slow wave and rapid eye movement sleep (REM) (e.g., Gradisar et al., 2011; Talbot et al., 2010; Scott et al., 2021; Short et al., 2020). Studies refer to this phenomenon as the epidemic of sleep deprivation (Millman, 2005) or the great sleep recession (Keyes et al. 2015).

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Cross-sectional (Johansson et al., 2016), longitudinal (Keyes et al., 2015) and actigraphy studies all show that adolescents get less than seven hours of sleep on average (Bei et al., 2014) and Bartel et al. (2015) conclude that more than 20% of adolescents report sleep disturbances. Without any restriction, adolescents would sleep an average of nine hours, but Bartel et al.'s (2015) meta-analysis found that only 14% to 27% obtain that amount of sleep during school nights. Fuligni and Hardway (2006) have also used the diary method to examine daily variations in 14- and 15-year-old adolescents. Although the average sleep duration of their sample was eight hours, they found large fluctuations, not only between school nights and weekends, but also within school days. The reasons are primarily physiological: the circadian sleep-wake system in adolescence and the homeostatic system responsible for sleep pressure are delayed (Carskadon, 2010; Illingworth, 2020). Adolescents are characterized by an evening chronotype and given a choice, would prefer late sleep and late wake (Illingworth, 2020). Contextual variables play an additional role in, as Carskadon (2010) calls it, a "perfect storm": parental control decreases, many leisure and academic activities occur in the evening, school typically begins early in the morning, and social media, an important means of connecting with others, cause adolescents to additionally postpone bedtime.

The Role of Sleep in Stable Mood and Mental Health of Youth

Adolescence is a sensitive period of development: a recent meta-analysis of 192 epidemiological studies by Solmi et al. (2022) has shown that 60% to 73% of mental health problems occur by the age of 24, while 40% of these are mood disorders. According to recent reports, the prevalence of mental disorders in youth aged 10 to 19 years is about 16%, with anxiety and depression being the most common, accounting for more than 55% of all mental health disorders in this age group (UNICEF, 2021). Sleep habits and mental health are closely linked. Sarchiapone et al. (2014) concluded in their large cross-sectional study of nearly 12,000 participants from 11 European countries that sleep deprivation is associated with emotional and behavioral problems, problematic peer relationships, greater anxiety, and suicidal ideation. Talbot et al. (2010) reported that inconsistent sleep habits were even related to objective indicators such as increased amygdala reactivity and decreased prefrontal cortex activity.

Loss of REM sleep, found in youth who tend to sleep less, was also related to repeated negative thinking patterns, more catastrophizing, impulsivity, hostile interpretation of social encounters, and a less favorable interpretation of positive activities (Gujar et al., 2011; Scott et al., 2021; Simon et al., 2020). In addition, several meta-analyses have found significant evidence that sleep deprivation is related to depression (Lovato & Gradisar, 2014) and anxiety in adolescents (Short et al., 2020; Baglioni et al., 2016). Not only did individuals with a history of sleep problems exhibit an increased risk of developing mood or psychotic disorders, but adolescents with depressive symptoms were more likely to be awake in bed at night, wake up more frequently, and report subjectively poorer sleep quality (Lovato & Gradisar, 2014; Scott et al., 2021).

Possibilities for an Objective Measurement of Daily Variations in Adolescent Sleep Behavior

Because both mental health problems and sleep behaviors are characterized by individual daily variations and different meanings regarding these daily changes to each person, youth research is increasingly interested in the temporal dynamics and interplay, which can be assessed using daily reports, passive data collection, and experience sampling methods (Keijsers & van Roekel, 2018; Nelson & Allen, 2018). Dejonckheere et al. (2019) as well as Niemeijer et al. (2022) conclude that researchers in the field are interested not only in how a person feels or behaves on average, but also in how often people's emotions and behaviors vary and how stable they are.

On a daily level, authors typically operationalize mental health as positive and negative affect (Houben et al., 2015). A group of Belgian-Dutch authors has formed an *Experience Sampling Item Repository* (https://esmitemrepositoryinfo.com/) and have conducted dozens of studies where they measured positive and negative affect with various adjectives (Dietvorst et al., 2021; Kirtley et al., 2019, Myin-Germeys et al., 2018). Since emotions fluctuate as changes in our environment occur, Dejonckheere et al. (2019) argue that it is important to capture their dynamics to make conclusions about individual differences in mental health or psychopathology. Houben et al. (2015) have shown that lower well-being is related with more variable and unstable emotions, especially when examining negative affect.

Because sleep is a complex phenomenon, researchers have combined different assessment methods to gain a comprehensive understanding of it, progressing from cross-sectional and longitudinal studies that relied on questionnaires or sleep diaries (Repetti et al., 2015; Sadeh, 2015) to higher accuracy with more sensitive measurement methods such as electrophysiological sleep methods (e.g., EEG and EMG) and polysomnography, performed under

laboratory and clinical conditions (Baglioni et al., 2016). Practical and methodological challenges led to the uptake of actigraphy and passive sensing that captures telephone data (Aledavood et al., 2019). Because phones have embedded sensors, using mobile phones to collect data also provides non-invasive behavior tracking without interrupting daily habits. Objective measurements are particularly important because previous studies have shown that participants' objective data and subjective reports sometimes do not match. Objectively measured sleep duration and time in bed showed a high correlation with subjective impressions (i.e., participants had accurate perceptions), but sleep quality and restfulness differed (Difrancesco et al., 2021). Nelson and Allen (2018) describe that smartphone-collected sleep data combined with experience sampling questionnaires can address previously stated methodological issues by combining subjective impressions and objective information. Furthermore, a combination of momentary assessments could also enable a deeper understanding of not only group but also individual differences.

Studies using daily reports suggest that better sleep quality predicts a higher positive affect and lower negative affect, but when it comes to sleep duration, which has often been found problematic in adolescents, shorter sleep duration, when measured objectively, was shown to predict inattention, and is not related to positive or negative affect. Moreover, results suggest the bidirectionality of these relationships; however, these still remain inconsistent (Bouwmans et al., 2017; Difrancesco et al., 2021; Hennig et al., 2017; van Zundert et al., 2015). Niemeijer et al. (2022) conducted a multiverse study in which they tested whether various mobile sensors (accelerometer, charging, light, physical activity, screen activity, and Wi-Fi) could predict subjective sleep quality, daily negative affect, and person-level depression. They concluded that it is possible to explain differences in subjective sleep quality, but the study had some limitations. For example, the sample was relatively small (N = 50) and consisted mainly of university students. In addition, the accelerometer only collected x-axis data, not y- and z-axis data. While the x-axis and the y-axis are parallel to the screen of the device, the z-axis is perpendicular to it. The difference between the x-axis and the y-axis is that the first axis aligns with the top and bottom edges, while the second axis aligns with the left and right edges. The combination of all three axes allows for the acquisition of more sensitive data.

The Current Study

Adolescents were of interest in only two of the aforementioned studies, and the authors of this paper are not aware of any ambulatory studies examining associations between affect and objectively measured sleep duration in Croatia or in the wider region. Furthermore, all these studies examined positive and negative affects, but not specific emotions. In this study, we mainly focused on exploring associations of objectively measured sleep duration and both positive and negative affects at the within-person and the between-person level in Croatian youth. Based on cross-sectional and prospective longitudinal studies, we hypothesized lower sleep duration to predict lower positive affect and higher negative affect on both within-person and between-person levels. To gain new insights into adolescent everyday sleep and affect, especially for Croatian conditions, we will use objectively measured sleep duration as a predictor. Our second aim is exploratory; i.e., we hope to obtain that lower sleep duration predicts lower levels of specific positive emotions and higher levels of specific negative emotions.

Methods

Participants

We conducted this study within a larger research project *Testing the 5C framework of positive youth development: traditional and digital mobile assessment* (P.R.O.T.E.C.T.), funded by the Croatian Science Foundation. A total of 102 first-year Croatian high school students participated in this study, with a mean age of 15.13 years (SD = 0.42; age ranging from 14 to 17 years). 64% of the participants were female, 32% were male, and 4% of the youth preferred not to indicate their gender. While half of the participants attended grammar school (i.e., an educational program that prepares for college), the other half attended a three-, four-, or five-year vocational school. All participants lived in Croatia, evenly distributed in terms of their place of residence: 35% of them lived in a large city, 35% in a small town, and 31% in a village.

Procedure

Approval for this study was obtained from the Ministry of Science and Education, the National Agency for Education, and the institutional ethics committee. We also procured active parental consent. Participants in the larger

longitudinal panel study were asked if they would also like to participate in a mobile study that will last eight days. If they expressed their interest by answering yes and leaving their e-mail address, they received an initial e-mail with information about the study design, the mobile app used, data to be collected, detailed instructions on how to install the EARS mobile app, and the code required to enroll in the mobile study.

The study was conducted utilizing the *Effortless Assessment Research System* mobile app (EARS) for Android and iOS developed by Ksana Health (Lind et al., 2018). This app uses the participants' personal smartphone for ecological momentary assessment, but also for passive data collection. More specifically, the app EARS collects data generated by the common use of the phone, such as accelerometer, geolocation, or screen time (Lind et al., 2018).

Each participant has been assigned a unique ID for this study, and only the first author had the information on which ID is associated with which specific email address. E-mail addresses were kept in a secured file and deleted from the final database. After the study was completed, all participants received a gift voucher worth €13.

Sampling Scheme and Compliance

The sampling scheme included eight days with one measurement per day. Data collection took place during the school semester but has included both school days and weekends. Participants received a signal at 10 am and were asked to report how they felt at the moment; i.e., their morning mood was measured. We decided to send the signal at 10 o'clock because at this time all schools have a longer lunch break between classes so the students could use their phones and were able to answer the questions. The questionnaire contained eight questions and was available to participants for the next five hours. Once a day, the data collected by the mobile sensors were encrypted and uploaded to the secured cloud.

Although 496 students expressed interest in participating in this study, only 142 (29%) of them installed the app EARS on their smartphones. Thus, 1,136 questionnaires were planned; however, participants only completed 590 (52%) of them. Since an intensive longitudinal study should include at least five measurements, only the participants who completed at least five questionnaires were included in the final database. Finally, there were 102 participants; i.e., 78% of the 142 students who installed the app completed the study.

Measures

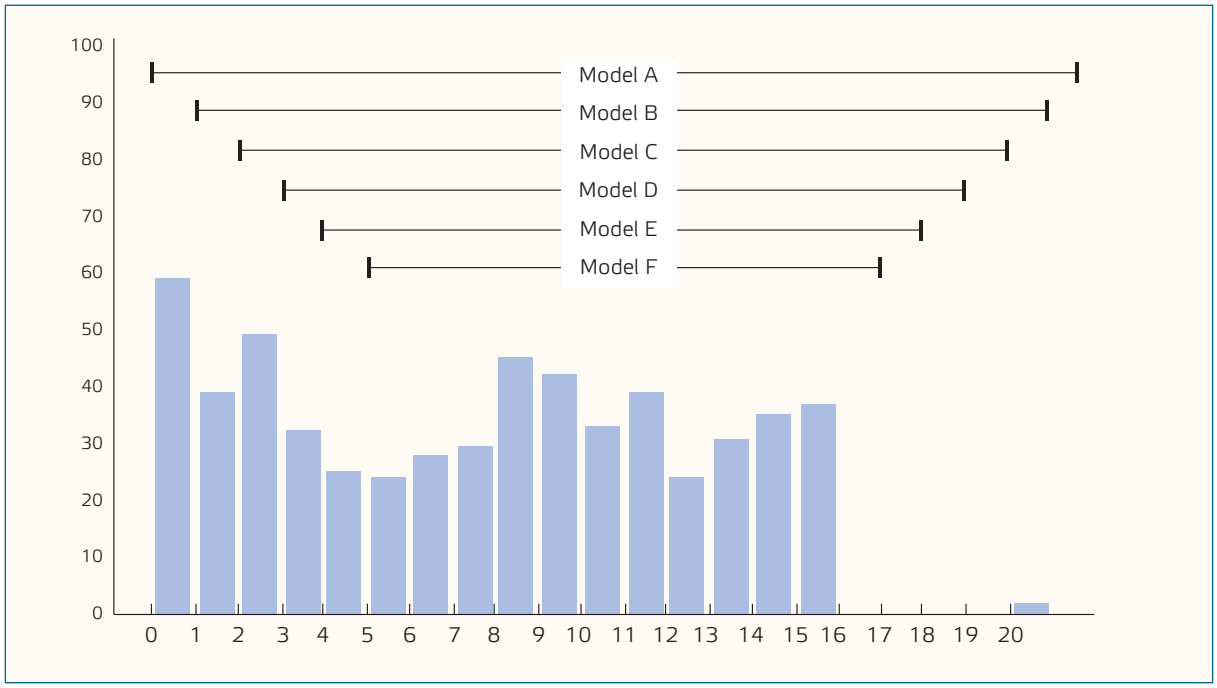
Affect

Participants' current affect was measured using an ad-hoc questionnaire including eight items that asked them how confident, tired, stressed, distracted, optimistic, worried, ashamed, and happy they felt at the moment. These items come from the Experience Sampling Item Repository; i.e. they have been used in previous studies by at least one of five different research groups in six different countries. Participants rated their emotions on a scale from 1 (not at all) to 5 (extremely). If the data are nested, it is recommended to analyze both within-subject and between-subject reliability, as estimates at one level do not reflect the true reliability of the scale unless the reliability is identical at both levels (Geldhof et al., 2014). The within-subject and between-subject reliability is estimated in a multilevel confirmatory factor analysis by using the TYPE = TWOLEVEL analysis in Mplus and adding model constraints (Geldhof et al., 2014). The positive affect was formed as a composite consisting of three items (confident, optimistic, and happy), showing a moderate reliability for the study sample at the within-person level (ω_{within} = .78) and a high reliability at the between-person level ($\omega_{between}$ = .88). The negative affect, on the other hand, was formed as a composite consisting of five items (tired, stressed, distracted, worried, and ashamed), but also showed a moderate reliability for the study sample at the within-person level (ω_{within} = .66) and a high reliability at the between-person level ($\omega_{between}$ = .93).

Sleep Duration

Sleep duration was measured objectively, using data collected by the accelerometer on participants' smartphones. Using a three-axis accelerometer, the app EARS provides data on bedtime, wake time, and sleep duration. This should provide more accurate information than a single-axis accelerometer used in previous studies; e.g., Niemeijer et al. (2022). Although subjective sleep duration was not estimated and it was not possible to verify the accuracy of the data collected, previous authors, such as Difrancesco et al. (2021) state that objectively measured sleep duration and time in bed showed a high correlation with subjective impressions. Sleep duration was reported in minutes.

Figure 1. Histogram of the sleep duration distribution from less than 1 hour to more than 20 hours



Notes: The horizontal axis represents sleep duration in hours; e.g. 0–1 hour, 1–2 hour, 2–3 hour, etc. The vertical axis represents the number of measurements in which certain hours of sleep occurred.

Statistical Methods

Although a three-axis accelerometer should provide accurate data on sleep duration, sleep duration in the present study ranged from 0 to 22 hours which has led us to question the most extreme result (see Figure 1). Therefore, the plausibility of the obtained results was tested statistically, rather than excluding some results as outliers without any criteria.

To check the robustness of the statistical results, we performed a multiverse analysis (Steegen et al., 2016), to examine models with different sleep duration. More specifically, five additional datasets were prepared in such a way that the minimum sleep duration was increased, and the maximum sleep duration was decreased by one hour in each subsequent model (see Figure 1). Altogether, six models were tested:

- Model A - sleep duration ranging from 0 to 22 hours (data from 451 measurement points),
- Model B - sleep duration ranging from 1 to 21 hours (data from 416 measurement points),
- Model C - sleep duration ranging from 2 to 20 hours (data from 397 measurement points),
- Model D - sleep duration in the range from 3 to 19 hours (data from 373 measurement points),
- Model E - sleep duration in the range of 4 to 18 hours (data from 349 measurement points),
- Model F - sleep duration in the range of 5 to 17 hours (data from 328 measurement points).

Intraclass correlations (ICCs) greater than .05 (González-Romá & Hernández, 2017) suggest that the relationship between sleep duration and emotions should be modelled at two levels; i.e., within-person and between-person. Therefore, multilevel regression models with sleep duration as predictor and positive affect, negative affect, and each of the eight emotions as criterion were estimated with TYPE=TWOLEVEL and ESTIMATOR=MLR in Mplus (version 8.8, Muthén & Muthén, 2017). Since Rhemtulla et al. (2012) suggested using the maximum likelihood method with five or more categories, and both the DWLS and MLR estimators seem to generate structural paths equally well (Li, 2021), we decided to treat emotions as a continuous scale and use the MLR estimator. In addition, multilevel regression models were estimated with the day of the week (school day vs. weekend) as a within-person predictor and gender, age, school type and place of residence as between-person predictors.

Results

Descriptive Statistics

As shown in Table 1, students slept an average of seven and half hours per day, with sleep durations ranging from less than an hour to as many as 22.5 hours. On average, adolescents reported the highest levels of happiness and the lowest levels of shame, with fatigue showing the greatest variability across days and participants. We tested whether the averages of personal mean scores regarding all variables differed on weekdays and weekends by performing t-tests for independent samples. In the participants' responses, no statistically significant differences manifested between school days and weekends for sleep duration (t = - 0.92, df = 244, p = .361) and for positive affect (t = - 0.96, df = 588, p = .337); however, negative affect was higher on school days (t = 3.02, df = 588, p = .003, d = .28; $M_{weekdays}$ = 2.38, $SD_{weekdays}$ = 0.93; $M_{weekends}$ = 2.13, $SD_{weekends}$ = 0.89).

Table 1. Descriptive Statistics for Sleep Duration, Positive and Negative Affect, and Specific Emotions

Variable	No. of occasions	Min	Max	M[1]	Mdn[2]	25th percentile	50th percentile	75th percentile	SD	ICC[3]
Sleep duration (in minutes)	580	0	1350	458.84	-	-	-	-	296.66	-
Positive affect	590	1	5	3.46	-	-	-	-	0.98	.54
Negative affect	590	1	5	2.31	-	-	-	-	0.92	.63
Confidence	587	1	5	3.44	3.00	3.00	3.00	4.00	1.16	.57
Optimism	589	1	5	3.34	3.00	3.00	3.00	4.00	1.16	.50
Happiness	589	1	5	3.59	4.00	3.00	4.00	4.00	1.13	.47
Fatigue	589	1	5	2.92	3.00	2.00	3.00	4.00	1.39	.57
Stress	590	1	5	2.41	2.00	1.00	2.00	3.00	1.33	.47
Distraction	588	1	5	2.4	2.00	1.00	2.00	3.00	1.26	.45
Worry	587	1	5	2.34	2.00	1.00	2.00	3.00	1.26	.42
Shame	586	1	5	1.5	1.00	1.00	1.00	2.00	0.86	.39

[1] Average of personal mean scores.
[2] Median of personal mean scores.
[3] Intraclass correlation.

Associations of Affect, Emotions, and Sleep Duration

The results of the multilevel regression (Table 2) show that objectively measured sleep duration did not correlate significantly with negative affect, fatigue, stress, worry, shame, or optimism, either at the within-person or between-person level. However, it was indicated that sleep duration serves as a significant positive predictor of positive affect, confidence, and happiness and a significant negative predictor of distraction at the within-person level. Thus, on days when the adolescents slept longer, they experienced a higher level of confidence, happiness, and positive affect as well as a lower level of distraction. In addition, longer sleep duration predicted less fatigue at the within-person level in the model in which sleep duration ranged from five to 17 hours.

Appendix A presents a summary listing the main outcomes of the multiverse analysis, while Appendix B illustrates how the p value varied from model A to model F, or in other words, how robust these results were. The robustness of the results was demonstrated in three of six models with different ranges of sleep duration for positive affect, happiness, and distraction. A significant effect for confidence was shown only in the base model, from which none of the outliers were removed.

To explain our results and see whether any demographic variables contribute to explaining the variance in affect and specific emotions, we decided to include a within-person variable; i.e., day of the week (school day vs. weekend), and between-person variables – gender, age, school type and place of residence – in our model (Table

3). Sleep duration remained a significant positive predictor of positive affect and happiness even after adding the new control variables, which indicates the robustness of these associations. Specific days of the week proved to be significant negative predictors of negative affect, stress, and distraction. In other words, adolescents experienced more stress, distraction, and negative affect than they do on typical school days.

At the between-person level, gender proved to be a predictor of confidence, stress, distraction, and shame. The results suggest that, on average, boys experience higher levels of confidence, and lower levels of stress, distraction, and shame. In addition, students from vocational schools reported higher levels of confidence, while adolescents from large cities reported higher levels of happiness and lower levels of fatigue and distraction.

Table 2. Results of the Multilevel Regression Analysis for Affect, Emotions, and Sleep Duration

	Within-person		Between-person	
	Est.	S.E.	Est.	S.E.
Positive affect	.12*	.05	-.09	.21
Negative affect	-.08	.05	.08	.24
Confidence	.10*	.05	-.10	.19
Optimism	.08	.04	-.01	.22
Happiness	.12*	.05	-.11	.24
Fatigue	-.09	.05	.31	.22
Stress	-.03	.05	.02	.24
Distraction	-.14**	.05	.27	.24
Worry	-.04	.05	-.06	.28
Shame	.08	.05	-.44	.27

Est. = standardized effects using STDYX standardization in Mplus; S.E. = standard errors of the parameter estimates using STDYX standardization in Mplus; significance based on two-sided p values of the unstandardized effects: * = $p < .050$, ** = $p < .010$

Table 3. Summary of the Main Outcomes for the Multiverse Analysis of the Within-Person and Between-Person Correlations of Affect and Emotions with Day of the Week, Sleep Duration, Gender, Age, School Type, and Place of Residence

	Weekday	Sleep duration		Gender	Age	School type	Place of residence
	Within-person	Within-person	Between-person	Between-person	Between-person	Between-person	Between-person
	Est. (S.E.)	Est. (S.E.)	Est. (S.E.)	Est. (S.E.)	Est. (S.E.)	Est. (S.E.)	Est. (S.E.)
Positive affect	.09 (.05)	.11 (.05)*	-.47 (.40)	-.25 (.21)	-.22 (.16)	.37 (.23)	.24 (.16)
Negative affect	-.19 (.05)**	-.08 (.06)	.39 (.46)	.32 (.22)	.16 (.20)	-.17 (.26)	-.29 (.18)
Confidence	.05 (.06)	.08 (.07)	-.25 (.27)	.37 (.13)**	-.23 (.11)*	.33 (.16)*	.12 (.12)
Optimism	.07 (.05)	.06 (.06)	-.10 (.33)	-.33 (.18)	-.18 (.15)	.12 (.19)	.05 (.14)
Happiness	.07 (.05)	.13 (.06)*	-.32 (.29)	-.25 (.15)	.02 (.11)	.22 (.18)	.25 (.12)*
Fatigue	-.02 (.06)	-.07 (.04)	.24 (.32)	.29 (.17)	.09 (.15)	.12 (.19)	-.26 (.13)*
Stress	-.19 (.06)**	-.04 (.05)	.18 (.32)	.36 (.17)*	.03 (.13)	-.13 (.20)	-.23 (.15)
Distraction	-.19 (.05)*	-.12 (.05)	.39 (.32)	.39 (.15)**	.15 (.22)	-.01 (.18)	-.34 (.14)*
Worry	-.11 (.05)	-.05 (.06)	.19 (.36)	.35 (.17)	.16 (.18)	-.33 (.18)	-.07 (.17)
Shame	-.04 (.06)	.06 (.06)	-.23 (.32)	.49 (.18)**	-.07 (.13)	.07 (.21)	.08 (.15)

Est. = standardized effects using STDYX standardization in Mplus; S.E. = standard errors of the parameter estimates using STDYX standardization in Mplus; significance based on two-sided p values of the unstandardized effects: * = $p < .050$, ** = $p < .010$

Discussion

Participants in the present study slept an average of seven and a half hours per day and showed wide variability in sleep duration, ranging from less than one hour to 22.5 hours, which is comparable with findings from Fuligni and Hardway (2006). Although the adolescents in the present study received optimal hours of sleep per night, as suggested by Paruthi et al. (2016), the variability in sleep duration suggests that sleep disturbances or at least inconsistent sleep patterns may be present.

We felt that distinguishing affect from specific emotions would provide a deeper understanding of the importance of sleep for mental health in adolescence, but we were not aware of any other studies that examined specific emotions. In the present study, sleep duration did not predict students' negative affect, but was a significant predictor of positive affect at the individual level. Studies subjectively measuring adolescents' sleep duration showed that shorter sleep duration predicted poorer mood in the morning and more anxiety symptoms the next day (Cousins et al., 2011; Fuligni & Hardway, 2006; Wrzus et al., 2014). Some authors (e.g., Cousins et al., 2011; Fuligni & Hardway, 2006) even found that the relationship between sleep duration and mood was bidirectional. On the other hand, Niemeijer et al. (2022) found that mobile sensor sensing data on sleep quality predicted subjective sleep quality far better than negative affect. It is possible that subjective sleep quality, and not the sleep duration, determines negative affect. Poor sleep and fatigue can reduce the cognitive abilities of adolescents and lead to a downward spiral in which poor sleep predicts negative affect and negative affect predicts the quality of sleep the next night (van Zundert et al., 2015). In addition, differences between our study and the previous studies may exist because previous studies examined early- and middle-aged adolescents, whereas the present study examined late-aged adolescents. While changes in academic, social, and biological systems lead to changes in sleep-wake rhythms in early adolescence (Carskadon & Acebo, 2002), late adolescents may develop socioemotional skills that could help them better withstand these changes. In other words, their coping skills may be less affected by poor sleep quality.

When it comes to emotions such as fatigue, stress, worry, shame, and optimism, it has to be noted that other daily studies mostly examined positive and negative affect, and not specific emotions. In the present study, participants have expressed more positive emotions, especially happiness, and fewer negative emotions, with fatigue being the most common. Since these are a person's average affect levels, this could indicate a healthy emotional functioning; i.e., we have included a general, healthy sample, experiencing more positive and fewer negative emotions. Authors of previous studies usually aggregated self-reported estimations of specific positive and negative emotions and it seems possible that statistically significant correlations occurred because of only some of the emotions combined in a measure of affect. The present results also support this: daily sleep duration seems to be related to daily happiness and distraction. A study from Henning et al. (2017) measuring adolescents' sleep duration subjectively showed that shorter sleep duration predicted more self-reported inattention. When compared to our study, we have found a similar pattern for distraction (which could relate to inattention) on a within-person level, meaning that when a person sleeps less than their own average, they feel more distracted.

In addition, in the present study, sleep duration only predicted positive affect, distraction, and happiness at the individual level. Although estimates on group level were high, no significant differences were found since standard errors that inform us on variability were high. This is not consistent with the work by Short et al. (2020), who conducted a meta-analysis including 73 studies and attempted to find causal contributions to positive and negative mood and emotion regulation. Their results, which included otherwise healthy youth, showed that less sleep was associated with a 55% higher likelihood of mood deficits: elevated anger, anxiety, and depressed mood, as well as fewer positive emotions. Our results underline the need for including individual approaches, especially when planning interventions. If individuals are educated to nurture their sleep regime, that could lead to more positive emotions on a daily level. The ability to nurture positive experiences even after shorter sleep nights might be crucial and our results could align with that (Gujar et al., 2011; Simon et al., 2020).

The effects of sleep duration on positive affect were found to be robust in three of the six models tested; i.e., they were not significant when the range of sleep duration was reduced to a minimum of three and a maximum of 19 hours of sleep. The same results were obtained for happiness and distraction. On the one hand, models with a narrower span of sleep duration may contain less measurement error, and robust effects should occur even in smaller samples. On the other hand, daily affect exhibits large variability, and the sample size, both of participants and of measurement points, may be important for error reduction. While Model A, in which sleep duration ranged from 0 to 22 hours, had 451 measurement points, Model D, in which sleep duration ranged from 3 to 19 hours and effects became insignificant, had 373 measurement points. These results suggest, therefore, some

interesting trends regarding the relationship between objective sleep duration and positive affect, happiness, and distraction, but should be replicated in a study encompassing more participants, more measurement points (both days and beeps on one day), and a combination of objective and subjective sleep duration information to verify the accuracy of the passive sensing data.

Additionally, in the present study, we tested whether within-person variables such as day of the week (school day vs. weekend), and between-person variables such as gender, age, school type, and place of residence, altered the percentage of variance in affect and specific emotions explained by sleep duration. Sleep duration remained a significant positive predictor of positive affect and happiness even after adding the control variables. In addition to sleep duration, the day of the week, gender, type of school and place of residence also play an important role in the adolescents' affect. The results suggest that school stress, for example school commitments, is associated with higher levels of negative affect, which is consistent with previous studies (see Scrimin et al., 2014). Additionally, Tsai (2019) reports cross-national evidence from 46 studies that workdays elicit more negative mood reports. Our study has shown that on average, boys experience higher levels of confidence and lower levels of stress, distraction, and shame. These findings are also consistent with gender differences in subjective well-being and mental health (Yoon et al., 2023). Students from vocational schools reported higher levels of confidence, which can be explained by less demanding schoolwork and more practical experience.

Strengths and Limitations

The greatest strength of the present study is the use of passive sensing data from participants' smartphones to measure their sleep duration. Most studies examining the relationship between sleep and mood, or mental health, have collected subjective reports of sleep duration. When participants are interviewed in daily diaries, they may provide accurate information, but passive data are likely to be more accurate. It should be noted, however, that these data are collected by sensors on the smartphone and are dependent on phone usage. That is, for example, if a person does not use the smartphone before going to bed, it is possible that this passive data is not entirely accurate. Additionally, due to technical problems in the collection of data from smartphone accelerometer, more measurement points were recorded for affect than for sleep duration. Therefore, the degrees of freedom for sleep duration differ from the degrees of freedom for positive and negative affect. Finally, we must question the long hours of detected sleep which is a very probable inaccuracy. The main limitation of this study lies in the fact that it did not combine objective and subjective measures of sleep, especially questions about the subjective perception of sleep duration, sleep disturbance and sleep quality that could shed more light onto an individual's perception of their sleep and how this relates to emotions. This would allow us to compare the effect of objective and subjective measures and their effects on affect, as well as to verify the accuracy of the data collected. This study did not account for circadian preferences and specific differences among adolescents, and that could also play a role in mood dynamics since it was measured in the first part of the day. An important flaw of this study consists in the fact that affect was measured once per day, in a manner of a diary study, and it would have been far more accurate had we used a design with multiple measurements per day. Nevertheless, diary study itself provides us a more accurate insight than one time survey measurement. Additionally, this study did not employ important items for negative affect that could also be valuable, such as sadness or loneliness.

Conclusions, Implications and Future Directions

Adolescents seem to express more positive affect and happiness as well as less distraction on days when they sleep longer. They also express higher levels of negative affect, stress, and distraction on school days. In addition, boys report more positive and fewer negative emotions on average. Although the results of the present study demonstrated moderate robustness in terms of the accuracy regarding measuring sleep duration with the accelerometer, they underscore the importance for studying the relationships between sleep quality and positive affect in adolescents' daily life. Future studies should combine objective and subjective measures of sleep, ideally with several measurements per day. In addition, focusing on specific emotions and including some emotions that were not considered in the present study, such as sadness or loneliness, would lead to a better understanding of the role that sleep plays in adolescents' mood. Finally, the inclusion of not only demographic variables but also personality variables – such as circadian preferences – would help to explain interindividual differences in the associations between sleep and affect. As it is well known, and as the current study again demonstrated, regular and adequate

sleep is important for adolescent well-being. Therefore, public health efforts to improve sleep health literacy in youth are an important avenue for investments.

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Author contribution
Lucija ŠUTIĆ: conceptualization, investigation, data management, formal analysis, interpretation, writing original draft.
Miranda NOVAK: conceptualization, methodology, funding acquisition, project administration, supervision, formal analysis, interpretation, supervision, writing original draft.

Declaration of interest statement
The authors declare that they have no conflict of interest.

Ethical statement
This manuscript is the authors' original work.
All participants engaged in the research voluntarily and anonymously.
Their data are stored in coded materials and databases without personal data.
The studies involving human participants were reviewed and approved by the Ethics Committee of the Faculty of Education and Rehabilitation Sciences of the University of Zagreb under 251-74/20-01/2.

Data Availability Statement
Datasets presented in this article are available from the corresponding author upon reasonable request.

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Appendix A

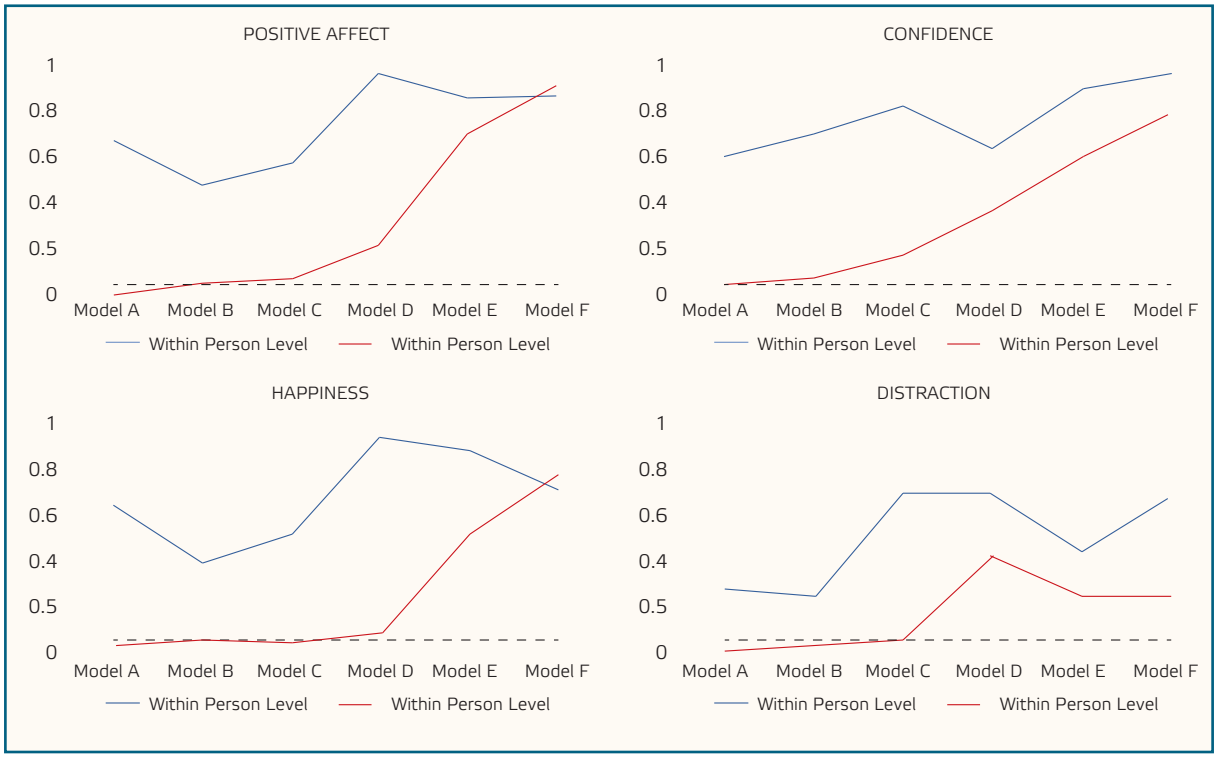
Summary of the Main Outcomes of the Multiverse Analysis Regarding the Within-Person and Between-Person Regressions of Affect, Emotions, and Sleep Duration

	Model A (0 to 22 hours of sleep)				Model B (1 to 21 hours of sleep)			
	Within-person		Between-person		Within-person		Between-person	
	Est.	S.E.	Est.	S.E.	Est.	S.E.	Est.	S.E.
Positive affect	.12*	.05	-.09	.21	.10*	.05	-.25	.35
Negative affect	-.08	.05	.08	.24	-.07	.06	.22	.42
Confidence	.10*	.05	-.10	.19	.08	.05	-.12	.33
Optimism	.08	.04	-.01	.22	.05	.05	-.24	.36
Happiness	.12*	.05	-.11	.24	.11*	.05	-.29	.34
Fatigue	-.09	.05	.31	.22	-.09	.05	.61	.41
Stress	-.03	.05	.02	.24	-.02	.06	-.05	.42
Distraction	-.14**	.05	.27	.24	-.13*	.05	.50	.43
Worry	-.04	.05	-.06	.28	-.03	.05	-.01	.50
Shame	.08	.05	-.44	.27	.07	.05	-.44	.41
	Model C (2 to 20 hours of sleep)				Model D (3 to 19 hours of sleep)			
	Within-person		Between-person		Within-person		Between-person	
	Est.	S.E.	Est.	S.E.	Est.	S.E.	Est.	S.E.
Positive affect	.11	.06	-.21	.37	.07	.06	.01	.23
Negative affect	-.07	.06	-.02	.36	-.03	.06	-.14	.23
Confidence	.08	.06	-.07	.34	.05	.06	.11	.22
Optimism	.06	.05	-.27	.38	.00	.05	-.06	.24
Happiness	.13	.06	-.23	.35	.12	.07	-.02	.23
Fatigue	-.08	.05	.49	.36	-.04	05	.24	.26
Stress	-.01	.05	-.32	.35	-.02	.06	-.31	.24
Distraction	-.12*	.06	.16	.41	-.05	.06	-.11	.27
Worry	-.04	.05	-.19	.42	-.03	.06	-.26	.28
Shame	.05	.05	-.48	.36	.07	.05	-.45	.23
	Model E (4 to 18 hours of sleep)				Model F (5 to 17 hours of sleep)			
	Within-person		Between-person		Within-person		Between-person	
	Est.	S.E.	Est.	S.E.	Est.	S.E.	Est.	S.E.
Positive affect	.02	.06	-.04	.20	.01	.06	-.03	.17
Negative affect	.00	.07	.08	.20	-.01	.06	.05	.17
Confidence	.03	.06	-.02	.20	.02	.06	.01	.16
Optimism	-.03	.06	-.09	.20	-.03	.06	-.15	.17
Happiness	.05	.07	.03	.20	.02	.07	.06	.17
Fatigue	-.05	.06	.26	.21	-.11*	.06	.24	.19
Stress	.04	.07	-.09	.22	.05	.07	-.08	.18
Distraction	-.08	.07	.17	.21	-.07	.06	.07	.18
Worry	.03	.07	-.06	.25	.07	.07	-.11	.21
Shame	.09	.05	-.18	.23	.07	.05	-.03	.22

Est. = standardized effects using STDYX standardization in Mplus; S.E. = standard errors of the parameter estimates using STDYX standardization in Mplus; significance based on two-sided p values of the unstandardized effects: * = $p < .050$, ** = $p < .010$

Appendix B

Line Chart of Unstandardized p Values of the Correlations Between Positive Affect, Confidence, Happiness, and Distraction with Sleep Duration



Note: The dashed line indicates p = .050.