Life Course Centre

The Australian Research Council Centre of Excellence for Children and Families over the Life Course

Phone +61 7 3346 7477 Email lcc@uq.edu.au lifecoursecentre.org.au

WORKING PAPER SERIES

THE EFFECTS OF SLEEP DURATION ON CHILD HEALTH AND DEVELOPMENT

Ha Trong Nguyen

Telethon Kids Institute and The University of Western Australia

Stephen R. Zubrick

Telethon Kids Institute and The University of Western Australia

Francis Mitrou

Telethon Kids Institute and The University of Western Australia

A more recent version of this paper was published as Nguyen HT, Zubrick SR, and Mitrou F. (2024) The effects of sleep duration on child health and development. Journal of Economic Behavior & Organization, 221, 35-51. DOI: 10.1016/j.jebo.2024.03.016

No. 2022-19

August 2022

Australian Government Australian Research Council

The University Of Queensland AUSTRALIA

The University of Melbourne

The University of Western Australia

The University of Sydney

NON-TECHNICAL SUMMARY

Humans spend approximately one-third of their lives sleeping, with children sleeping more than adults. A large scientific literature repeatedly attests to the association between a range of sleep qualities – including the amount of time – and aspects of child development. And yet, studies that more directly estimate the causal effects of time sleeping on various health, cognitive and non-cognitive outcomes in children and adolescents are scant. This paper examines the causal impact of sleep duration on health and development of children and adolescents.

Using over 50 thousand time use diaries from two cohorts of Australian children spanning over 16 years in the Longitudinal Study of Australian Children (LSAC) survey, we first document that, on days with longer daylight duration, children sleep significantly less, partly by going to sleep later and waking up earlier. On such days, they also reduce the time allocated to personal care or media activities and increase the time to school or physical activities. We present new evidence indicating that the effects of daily daylight duration on sleep duration are greater for females, older individuals, children of employed mothers or on weekends/holidays.

We then exploit variations in local daily daylight duration measured on pre-determined diary dates across the same individuals through time to draw causal estimates of sleep duration on a comprehensive set of child development indicators. We find that sleeping longer improves selected general developmental and behavioural outcomes. Our results also reveal that sleeping more increases the probability of having excellent health or decreases the likelihood of having any ongoing condition. By contrast, sleeping longer statistically significantly increases BMI scores, mainly by increasing the risk of being overweight. Furthermore, the results show statistically insignificant or a relatively small positive impact of sleeping more on cognitive development.

The findings presented in this paper highlight the importance of addressing potential endogeneity of sleep duration when quantifying its impact on child developmental outcomes. The findings of substantial health and development benefits of sleeping longer from this study reinforce the need to formulate policies to reduce sleep deprivation in young individuals, especially in females and adolescents who appear to benefit more. This paper also identifies potentially detrimental effects of sleeping longer on some developmental outcomes, including increased BMI and a higher risk of being overweight for males, and these side effects should be considered when designing such policies.

ABOUT THE AUTHORS

Ha Nguyen is a Senior Research Fellow at the Telethon Kids Institute. He is also an Adjunct Senior Research Fellow at Centre for Child Health Research, the University of Western Australia, and a Research Fellow in the Life Course Centre. His general research interests have focused on applied econometrics, particularly in the fields of health economics and labour economics. He has published widely in both academic and policy outlets, with articles appearing in high-ranking economics journals, including Journal of International Economics, Health Economics, American Journal of Health Economics, Labour Economics, Economics of Education Review, and Economic Record. Email: ha.nguyen@telethonkids.org.au

Stephen R. Zubrick is an Emeritus Professor and Senior Honorary Research Fellow at the University of Western Australia and a Senior Advisor at the Telethon Kids Institute. He is an elected Fellow of the Academy of Social Sciences in Australia and a Fellow of the Australian Academy of Medical and Health Sciences. He specializes in creating and executing large-scale state and national cross-sectional and longitudinal studies of child and family development. Email: Stephen.Zubrick@telethonkids.org.au

Francis Mitrou is Research Program Head–Population Health, at Telethon Kids Institute. He is also Associate Professor at the Centre for Child Health Research, at The University of Western Australia, and a Chief Investigator in the ARC Life Course Centre. Beginning as an economist with the Australian Bureau of Statistics before entering academia, he has expertise in national population surveys, linked administrative data, Indigenous health and wellbeing, and economic evaluation, with a focus on child and adolescent development, social disadvantage and life course trajectories. Email: Francis.Mitrou@telethonkids.org.au

Acknowledgements

This research was partly funded by the Australian Research Council Centre of Excellence for Children and Families over the Life Course (#CE200100025). This paper uses unit record data from Growing Up in Australia, the Longitudinal Study of Australian Children. The study is conducted in partnership between the Department of Social Services (DSS), the Australian Institute of Family Studies (AIFS) and the Australian Bureau of Statistics (ABS). The findings and views reported in this paper are those of the author and should not be attributed to the DSS, the AIFS or the ABS.

DISCLAIMER: The content of this Working Paper does not necessarily reflect the views and opinions of the Life Course Centre. Responsibility for any information and views expressed in this Working Paper lies entirely with the author(s).

ABSTRACT

This paper studies the extent to which sleep duration causally affects health, cognitive and non-cognitive development in children and adolescents. Using over 50 thousand time use diaries from two cohorts of Australian children spanning over 16 years, we first document that children sleep significantly less on days with longer daylight duration, partly by going to sleep later and waking up earlier. We then exploit variations in local daily daylight duration measured on pre-determined diary dates across the same individuals through time as an instrument in an individual fixed effects regression model to draw causal estimates of sleep duration on a comprehensive set of child development indicators. Our results show that sleeping longer improves selected general developmental, behavioural and health outcomes in children and adolescents. By contrast, sleeping more statistically significantly increases their BMI scores, mainly by increasing the risk of being overweight. Moreover, while the impact of sleep duration on general and behavioural outcomes is more pronounced for females or older individuals, the effect on BMI is largely driven by males. The results indicate a null or relatively small positive impact of sleeping longer on cognitive skills.

Keywords: Sleep; Time Allocation; Circadian Rhythms; Human Capital; Child Development

Suggested citation: Nguyen, H.T., Zubrick, S.R. & Mitrou, F. (2022). 'The effects of sleep duration on child health and development', Life Course Centre Working Paper Series, 2022-19. Institute for Social Science Research, The University of Queensland.

1. Introduction

Humans spend approximately one-third of their lives sleeping, with children sleeping more than adults (Ohayon et al. 2004; Hirshkowitz et al. 2015). Given time is a scarce resource, individuals make choices about how they allocate time to sleep (Biddle & Hamermesh 1990). Because optimal sleep is a biological necessity, an understanding of the consequences of choices made by individuals (or for them) about time spent sleeping is of value in recommending health advice specifically, but also more broadly to aspects of human development – particularly that of children and young people. A large scientific literature repeatedly attests to the association between a range of sleep qualities – including the amount of time – and aspects of child development (see Section 2 for a literature review). And yet, studies that more directly estimate the causal effects of time sleeping on various health, cognitive and non-cognitive outcomes in children and adolescents are scant (see, for instance, recent reviews by Matricciani et al. (2019) or Jagnani (2022)). This paper examines the causal impact of sleep duration on health and development of children and adolescents. It contributes to a rich literature examining the relationship between sleep and child health (Chaput et al. 2016) and a growing literature on the association between sleep and academic performance (Dewald et al. 2010; Matricciani et al. 2019) in two important ways.

First, this paper moves beyond observational studies of association to more directly address unobservable individual heterogeneity and reverse causality issues (Wooldridge 2010) by employing a new empirical model to estimate the causal impact of sleep duration on child development. Particularly, we exploit variations in local daily daylight duration measured on pre-determined diary dates across the same individuals over time as an instrument in an individual fixed effects (FE) regression model to draw causal estimates of sleep duration on child development indicators. Motivated by medical research on circadian rhythm (Reppert & Weaver 2002; Roenneberg et al. 2007), previous studies have successfully employed solar cycle-based instruments in an instrumental variables (IV) approach to identify the causal impacts of adults' sleep duration (Giuntella et al. 2017; Gibson & Shrader 2018; Kajitani 2021). Our paper is the first to adopt this IV identification strategy to explore the impact of sleep duration in children and adolescents. Unique to the related literature, we augment this IV approach by applying it to an individual FE regression model, effectively controlling for time-invariant factors which may be simultaneously associated with the instrument and child developmental outcomes.

Second, this paper presents causal evidence of the impact of sleep duration on an extensive list of child developmental outcomes. Prior studies have focused on a limited range of child development outcomes, potentially due to data constraints (Taras & Potts-Datema 2005; Matricciani et al. 2019). This would provide an incomplete picture of the potential impacts of sleep duration which may have differential effects on specific outcomes of interest (Fiorini & Keane 2014; Nguyen et al. 2022a). To provide a more complete picture, we utilise high-quality longitudinal data with rich information on both child sleep and development outcomes. In particular, we quantify sleep duration using time-use diaries, which are considered one of the most accurate tools to record time allocation (Frazis & Stewart 2012), from two cohorts of children observed on multiple occasions over 16 years. During the same period, our data also contain a rich suite of child development outcome measures, including general development, health, anthropometric measures, health expenditures, and cognitive test scores. Many of these outcomes were objectively measured or available via linked administrative data sources and hence are less prone to measurement errors. By providing evidence of the impact of sleep duration on a comprehensive set of outcomes in one unified framework, this paper depicts a much broader picture of the effects of sleep duration than previously possible, providing important insights for the design of sleep recommendations for children and adolescents (Paruthi et al. 2016).

Employing 16-year data from the Longitudinal Study of Australian Children (LSAC) survey, we first document that, among three daily solar cycle variables of daylight duration, sunrise time and sunset time, the sleep duration of children and adolescents is most responsive to daily daylight duration. On days with longer daylight duration, children sleep significantly less, partly by going to sleep later and waking up earlier. On such days, they also reduce the time allocated to personal care or media activities and increase the time to school or physical activities. We present new evidence indicating that the effects of daily daylight duration on sleep duration are greater for females, older individuals, children of employed mothers or on weekends/holidays.

Using a fixed-effects instrumental variables (FE-IV) approach, we find that sleeping longer improves selected general development, behavioural and health outcomes in children and adolescents. By contrast, sleeping more increases their Body Mass Index (BMI), mainly by increasing the likelihood of being overweight. Moreover, while the general and behavioural developmental benefits of sleeping longer concentrate among females or older individuals, the potentially detrimental effects of sleeping longer on BMI are only observed for males. The results further suggest a null or at most small positive impact of sleep duration on cognitive skills. Finally, we find our results robust to a series of sensitivity

tests, including employing alternative instruments or additionally controlling for numerous time-variant observable factors.

The rest of this paper is structured as follows. Section 2 provides a brief review of related studies and Section 3 describes the data we use. We then present our empirical results in two pieces. First, Section 4 documents how children and adolescents adjust their time in response to changes in daily solar cycles. Second, Section 5 empirically quantifies the impacts of sleep duration on numerous child developmental outcomes. Section 6 presents robustness checks and additional findings while Section 7 concludes.

2. Literature Review

Our empirical work is theoretically motivated by a relatively small number of economics contributions on sleep. For instance, building on the work of Becker (1965) on time allocation and Grossman (1972) on demand for health, Biddle and Hamermesh (1990) develop an optimal model of time allocation among work, leisure and sleep. Two main implications from the seminal work by Biddle and Hamermesh (1990)'s model are: (i) sleep duration affects the amount of time allocated to other activities, and (ii) higher labour productivity increases the opportunity cost of sleep time. As Biddle and Hamermesh (1990)'s model is developed primarily to explain sleep choices in the working-age population, Jagnani (2022) extends this model to predict sleep choices of children. It is clear from these theoretical frameworks that, regardless of who makes the decision about how long to sleep, sleep is a choice variable, suggesting a need to properly control for endogeneity of sleep when quantifying its causal impact on outcomes of interest. However, these theoretical frameworks provide ambiguous predictions about the direction, as well as the magnitude, of sleep effects on developmental outcomes in young individuals. As such, it remains an empirical issue to determine to what extent sleep affects developmental outcomes.

There is a rich literature exploring the effects of sleep on adults (Watson et al. 2015) and children (Chaput et al. 2017; Matricciani et al. 2019; Schlieber & Han 2021). Most of this literature is from non-economics fields, and concerns the effects of sleep on children's developmental outcomes, producing mixed results, reflecting differences in sleep measures, developmental outcomes and empirical methods employed by prior studies (see, for example, Matricciani et al. (2019) for a recent meta review). This literature has been criticised for relying on correlational cross-sectional designs (Matricciani et al. 2019). Thus, despite a large literature documenting the relationship between sleep

and child development, we remain uncertain about the causal impact of sleep on health, cognitive and non-cognitive outcomes in children and adolescents.

Quantifying the causal impact of sleep is challenging due to problems related to unobserved heterogeneity and reverse causality (Wooldridge 2010). Specifically, there are unobservable individual characteristics (such as the individual's time preferences or genetic factors) which are correlated with both the child's sleep and their development. Reverse causality is a threat to estimate validity as it is uncertain whether the child's sleep influences development or vice versa. To overcome these research challenges, previous studies have employed experimental research designs (Van Dongen et al. 2003; Lo et al. 2016; Beebe et al. 2017; Bessone et al. 2021) or instrumental variables methods (Giuntella et al. 2017; Gibson & Shrader 2018; Costa-Font & Fleche 2020; Kajitani 2021)[1].

Three studies which use solar cycles-based instruments share commonalities with our empirical approach[2]. Gibson and Shrader (2018) use daily sunset time recorded on the diary date as an instrument to explore the impact of sleep duration on earnings in the US. Likewise, Giuntella et al. (2017) employ yearly average sunset time at a local level as an instrument to study the effects of sleep duration on cognitive skills and depression symptoms of older workers in urban China. More recently, Kajitani (2021) exploits the annual variation in the average daylight duration between cities as an instrument to examine the impact of sleep duration on labour market outcomes of Japanese men.

These IV studies focus on adults' sleep so the current paper establishes itself as the first to adopt this IV identification strategy to explore the causal impact of sleep duration in children and adolescents. We augment this IV approach by applying it to an individual FE regression, effectively addressing an unresolved concern that time-invariant unobservable factors co-vary with both the instrument and outcomes of interests.

Our empirical approach is also relevant to those of studies which exploit exogenous sleep induced by sunset time or daylight-saving times (DST) transitions to examine the impact of sleep on adult health (Giuntella & Mazzonna 2019; Jin & Ziebarth 2020), adult economic performance (Giuntella &

[1] Experimental studies, particularly on students (Lo et al. 2016; Beebe et al. 2017), are not without criticism because their results may not be generalized well to real-world settings (Matricciani et al. 2019).
[2] Using UK data, Costa-Font and Fleche (2020) employ child sleep disruption as an instrument to examine the effect of maternal sleep duration on her labour market outcomes in an individual FE-IV model.

Mazzonna 2019), automobile accidents (Smith 2016), adults' voting behaviours (Holbein et al. 2019) or children's cognitive scores (Jagnani 2022)[3]. To deal with the fact that sleep and outcomes of interest are not available in one common dataset, these studies have to employ a reduced-form regression approach (i.e., by including sunset time or DST transitions as an explanatory variable in the outcome equation). This reduced-form approach can only reveal the indirect impact of sleep and may lead to uncertainty in the magnitude of the actual impact of sleep on such outcomes.

In searching for the most suitable instrument for our empirical model, we provide a comprehensive analysis of the impact of time of sunrise, time of sunset and total duration of sunlight (i.e., herein "daily solar cycles") on time allocation of children and adolescents. We contribute to a rich literature on the relationship between solar cycles and sleep (Harrison 2013; Mattingly et al. 2021) and the emerging literature examining the impact of solar cycles on time allocation to sleep and other activities in adults (Hamermesh et al. 2008; Gibson & Shrader 2018) and children (Jagnani 2022) in three key aspects. First, to the best of our knowledge, this paper is the first to exclusively examine the effects of daily solar cycles on time allocation of young individuals in a developed country like Australia. Jagnani (2022) provides the earliest evidence on the impact of daily sunset time on Indian children's sleep and other time uses. Such evidence from a developing country may not be generalized well to other developed countries, including Australia. Second, and distinct from existing studies which employ cross-sectional data (Hamermesh et al. 2008; Gibson & Shrader 2018; Jagnani 2022), our paper uses panel data and an individual FE model to effectively control for time-invariant factors that co-vary with daily solar cycles and time allocation. Third, our extensive heterogenous analysis reveals novel insights into differential impacts of daily solar cycles on time allocation of children and adolescents.

3. Data

We use time-use diaries (TUD) from two cohorts of children surveyed in the Longitudinal Study of Australian Children (LSAC) to document time allocation patterns of children and adolescents. The LSAC

[3] There are several related studies concerning the effects of school starting time on test scores (Carrell et al. 2011; Edwards 2012; Minges & Redeker 2016; Heissel & Norris 2018). These studies rarely observe students' sleep or other time uses. This paper is also related to studies examining impacts of time allocation to other activities, such as media (Gentzkow & Shapiro 2008; Nieto & Suhrcke 2021) or physical activities (Nguyen et al. 2022b) on development of young individuals.

is a biennial nationally representative survey with a sampling frame of all children born between March 2003 and February 2004 (Birth or B-Cohort, 5,107 infants aged 0–1 year in 2004) and between March 1999 and February 2000 (Kindergarten or K-Cohort, 4,983 children aged 4–5 years in 2004). The LSAC began in 2004 and the most recent wave 9 was surveyed in 2020/21 (Mohal *et al.* 2021).

TUDs embedded in the LSAC also were collected biennially (see Appendix Table A2 for LSAC contents by wave and cohort). There are four major changes to TUDs during the study period which are worth mentioning. First, in each of the first three waves of LSAC, the corresponding parent was given two TUDs (one on a weekday and one on a weekend day) to complete on the study child's activities. However, from wave 4 onwards, each family was given one TUD to complete each wave. Second, activities are recorded according to 96 15-minute slots in the first three waves, while activities are reported in the form of an "activity episode" diary from wave 4 onwards (See Corey *et al.* (2014) for examples of TUDs). Third, from Wave 4 onwards the study child was requested to fill in the TUD via computer assisted interview. Fourth, K cohort children were requested to complete TUDs in the first six waves while B cohort children were not asked to do so in waves 4, 5 and 9. The available TUDs enable us to study the topic over a 16-year period for study children and young people aged from birth (for B cohort) or 4/5 years old (for K cohort) up to 15/16 years old (for both cohorts).

We employ three variables to describe sleep patterns of children and adolescents. The first and primary variable is sleep duration which is calculated by summing all time slots or episodes recorded as sleep or napping during the diary date (Appendix Table B1 and Appendix Table B2 provide detailed activity classifications). Our sleep duration variable captures the "actual" time spent on sleeping/napping as it excludes time spent in bed awake. We measure sleep duration in hours per day. The second variable is sleep onset time[4] which is constructed from responses to a question explicitly asking about the time the study child went to sleep on the diary date. Similarly, we employ responses to a question asking about the time the study child woke up on the diary date to construct the third variable which describes the child's wakeup time. We measure sleep onset time and wakeup time in hours, following the 24-hour clock. Unfortunately, the questions about the time the study child went to sleep or woke up were not asked in the first three waves of LSAC. For these waves, we assign the

[4] We use "sleep onset time" instead of "bedtime" to reflect that our sleep duration measure excludes time spent in bed awake. Due to sleep interruptions during nighttime and sleeping/napping outside nighttime, sleep duration is not necessarily the same as the difference between wakeup time and sleep onset time.

first time slot recorded with activities other than sleep from midnight as wakeup time. Moreover, we allocate the first time slot recorded as sleep between the sunset and sunrise time calculated for the diary date (see Section 0 for constructions of sunrise and sunset time) as sleep onset time.

To provide a more complete picture of how children and adolescents allocate their time in response to daily solar cycles, in addition to the three sleep-related variables described above, we use TUDs to construct other grouped activities during the same diary date. In particular, following previous studies (Fiorini & Keane 2014; Nguyen *et al.* 2022a), to have an informative and manageable analysis, we aggregate pre-coded activities into seven other activity groups, namely personal care, school, education, physical activity, chores, media and travel.[5] Personal care consists of awaking in bed, eating/drinking, showering/bathing and undertaking non-physical non-educational activities. School includes time spent on day care centre/playgroup or organised school lessons. Education relates to educational activities outside of school, such as reading or being read to, doing homework and attending private lessons. Physical activities refer to time allocated to walking, cycling or attending organised sport activities while chores consists of time spent on household chores or work. Media activities include watching TV programs or movies/videos, playing video games, using computer and internet (unrelated to doing homework) and communicating via electronic devices. Travel refers to time spent on transit.

From an initial sample of about 55 thousand TUDs collected across Waves 1 through 8, we exclude TUDs with obviously incorrect entries or incomplete information. We also exclude TUDs with missing information on basic explanatory variables that we control for in the regressions (see following sections). Final sample sizes aggregated across the 8 Waves vary by empirical models or developmental outcomes considered. For example, the sample size used to examine the relationship between daily solar cycles and children's time allocations includes 53,741 complete TUDs, from 8,708 unique children (with 4,356 unique children from B cohort).

[5] As have been done in previous studies (Fiorini & Keane 2014; Nguyen *et al.* 2022a), we focus on main activities to ensure that the total time allocated to all grouped activities do not exceed 24 hours per day. From wave 4 onwards, the respondent was asked to identify the main activity undertaken and we use this information to identify main activities. However, such information is not available in the first three waves of LSAC. Arming with an observation from other waves showing that most frequent secondary activities are eating, drinking, talking face-to-face and watching TV, for time slots with multiple activities recorded, we arbitrarily classify which activity as main.

Summary statistics, reported in Appendix Table A1 and Appendix Figure A1, show that, on average, children and adolescents in our data spend about 10.5 hours per day on sleeping and this activity represents the largest share of time spent on all grouped activities undertaken during the 24 hours. Furthermore, they typically go to sleep at around 8 PM and wake up at 7 AM. It should be noted that, while being recorded on one day, sleep variables derived from LSAC TUDs are likely to capture sleep behaviours on a longer horizon for two main reasons. First, 67% of TUDs are explicitly stated as being recorded on an "ordinary" day. Second, three main sleep-related variables used in this paper are statistically significantly correlated with other sleep-related variables which are measured over a longer period, such as "during the last month", "regular times" or "usual" time, and are available in LSAC (See Appendix Table A3).[6] Appendix Table A3 additionally reports statistically significant correlations between sleep duration and some variables describing sleep adequacy, sleep routine or sleep quality. For instance, the significant correlations suggest individuals with a longer sleep duration are more likely to report that they have enough sleep or have a sleep routine. Moreover, individuals who sleep longer are more likely to feel that they sleep well.

4. Daily solar cycles and children's time allocation

4.1 Empirical model

We employ the following model to examine how children and adolescents adjust their time in response to variations in daily solar cycles:

$$T_{it} = \alpha + S_{i(p)t}\beta + X_{it}\gamma + \delta_i + \mu_{it} \qquad (1)$$

Here T_{it} is a time allocation measure that individual i in postcode p on diary date t, $S_{i(p)t}$ is a variable indicating daily solar cycles on that date in that postcode, X_{it} is a vector of individual and local level time-variant controls, δ_i is an individual time-invariant factor, and μ_{it} is an error term. α, β and γ are vectors of parameters to be estimated.

We include in X_{it} a rich set of characteristics which have been shown to be associated with children's time allocation (Nguyen *et al.* 2021b; Nguyen *et al.* 2022a). These include the individual's

[6] We do not use these sleep-related variables in the main analysis because they are not frequently available enough for us to apply our empirical method (see Appendix Table A2 for descriptions and availability of main variables). For the same reason, we do not use other developmental outcomes available in LSAC in this paper.

characteristics (e.g., age and its square, gender, Aboriginal status, low birthweight), the household's characteristics (e.g., maternal migration status, maternal education, number of siblings and two-parent households), and neighbourhood characteristics.[7] We additionally control for seasonal or spatial differences in time allocation by including TUD quarter,[8] year and state/territory dummies in Equation (1). The inclusion of state/territory dummies additionally controls for different time zones across Australia. To capture likely variations in time use patterns throughout the week, we further include in X_{it} a series of day-of-week dummies and an indicator describing whether the diary was completed on holidays.

We employ three variables to represent daily solar cycles: daylight duration, sunrise time and sunset time. We measure daily daylight duration in hours per day and the other two variables in hours, according to the 24-hour clock. These three variables are calculated using the diary date, geographic coordinates (i.e., longitude and latitude) of the child's residential postcode centroid, daylight saving adjusted time zone offsets and astronomical algorithms developed by Meeus (1999).[9] Because these variables are highly correlated, we introduce each of them separately in Equation (1). Moreover, we consider each of the 10 time-use variables described in Section **Error! Reference source not found.** as a separate outcome in Equation (1).

We exploit the panel nature of the data to estimate Equation (1) using an individual fixed effects (FE) method. Standard errors are clustered at the individual child level to account for potential intertemporal correlations. The parameter of interest from this regression is β which captures the short-term[10] impact of daily solar cycles on time allocation. The identification source of β comes from changes in daily solar cycles recorded on multiple diary dates of the same individuals over time. Our empirical model improves on previously employed models in related literature (Gibson & Shrader 2018; Jagnani 2022) by effectively controlling for individual time-invariant factors that may be

[7] These include percentages of individuals having an Aboriginal/Torres Strait Islander origin, speaking English, being born in Australia or completing year 12 in linked areas, percentages of households with household income less than AU$1,000/week in linked areas, a metropolitan dummy. All time-invariant variables are dropped from the individual FE regressions.

[8] We obtain very similar results using season dummies instead of quarter dummies.

[9] Similar astronomical algorithms have been employed in previous studies (Giuntella *et al.* 2017; Gibson & Shrader 2018). We use a STATA command written by Gibson and Shrader (2018) to perform this task.

[10] We focus on "short-term" impact of daily solar cycles in this paper because any long-term impact would be absorbed in this individual FE model (Giuntella *et al.* 2017; Gibson & Shrader 2018).

simultaneously correlated with the daily solar cycle variable and time allocation. As discussed by Gibson and Shrader (2018), one of such time-invariant unobservable factors would be residential sorting as individuals may self-select into different locations based on their responsiveness to solar cycles. Another potentially important time-invariant factor would be persistent reporting bias (Wooldridge 2010; Frazis & Stewart 2012).

4.2 Empirical results

We begin by graphically examining the relationship between each of the three daily solar cycle variables and the three sleep-related variables. Appendix Figure A2 represents distributions of three sleep variables by daily daylight duration, showing that longer daylight durations shift the distribution of sleep duration or wakeup time leftward and the distribution of sleep onset time rightward. These movements are consistent with the view that longer daylight duration may decrease sleep duration, with individuals going to sleep later and waking up earlier. Consistent with this pattern, an earlier sunrise time may also decrease sleep duration by inducing individuals to rise earlier and go to sleep later[11] (see Appendix Figure A3). Moreover, we observe from Appendix Figure A4 that a later sunset time may also reduce sleep duration, primarily by causing individuals to go to sleep later.

Table 1 presents FE estimates of each of the three daily solar cycle variables from regressions of ten time use indicators.[12] The first panel in Table 1 reports the results for daily daylight duration, suggesting that children and adolescents sleep statistically significantly less on days with longer daylight duration. Specifically, an increase of one hour in daylight duration is associated with a decrease of 0.07 hours (or 4.2 minutes) in sleep duration per day. This estimate is quite substantial in magnitude since an increase of 6 hours in daylight duration (i.e., the maximum variation of daylight duration observed in our data) can reduce sleep duration by 25 minutes per day (or 4% of sample mean). Moreover, the regression results on sleep onset time and wakeup time indicate that the reduction in sleep duration is partly explained by the pattern that, on days with longer daylight

[11] Early sunrise typically coincides with late sunset and this late sunset may induce individuals to go to sleep later.

[12] Estimates for other variables, reported in Appendix Table A4, are as expected and in line with that in previous studies (Nguyen *et al.* 2021b; Nguyen *et al.* 2022a). For instance, time allocated to sleep, personal care and media decreases with age while time spent on school increases with age. Moreover, children's time allocations are statistically significantly affected by some household characteristics, including the number of siblings and living with both parents, days of the week or survey quarters.

duration, individuals go to sleep later and wake up earlier. Numerically, a one-hour-increase in daylight duration causes individuals to go to sleep 5.4 minutes later and wake up 2.4 minutes earlier.

The combined effect of daylight duration on sleep onset time and wakeup time suggests that if children had slept continuously at nighttime, a one-hour-increase in daylight duration would have decreased nighttime sleep duration by 7.8 minutes per day, a figure which is higher than the estimated effect of a similar increase in daylight duration on sleep duration of 4.2 minutes. Because our sleep duration measure excludes sleep interruptions but includes naps, this disparity suggests that children can partly compensate for the sleep loss due to longer daylight duration by taking naps during the day. Other estimates reported on the first panel of Table 1 describe that, on days with longer daylight duration, children spend statistically significantly more time on school and physical activities and less time on personal care and media activities.

The second and third panel in Table 1 reports children's time allocation responses to sunrise time and sunset time, respectively. The results show that a later sunrise time increases sleep duration, partly by inducing children to go to sleep earlier and wake up later. The estimates of sunrise time on non-sleep variables further suggest that this increase in sleep duration is collectively explained by a decrease in school or physically active time and an increase in personal care or media time. By contrast, and in line with that in a study of Indian children aged 6-14 years old by Jagnani (2022), our results indicate that a later sunset time statistically significantly decreases the time children spend on sleeping, partly by influencing them to go to sleep later. Interestingly, despite clear differences in data, empirical methods and institutional contexts among studies, the pattern that wakeup time is less responsive to solar cues than sleep onset time is also observed in studies focusing on adults in the United States (Hamermesh *et al.* 2008; Giuntella & Mazzonna 2019). Our results further indicate that a later sunset time also causes children to reduce the time allocated to personal care or media activities and increase the time to school or physical activities.

The above results suggest that sleep duration is more responsive to changes in daily daylight duration than to daily sunset time or daily sunrise time. This pattern is in line with the fact that both daily sunrise and sunset time matters for children's sleep duration in Australia. It is also supported by the results from a *t* test for statistical significance of each of the three daily solar cycle variables which show that F statistic is greatest for daily daylight duration. Because sleep duration is most sensitive to daily daylight duration among the three daily solar cycle variables considered here, to strengthen the statistical power of the analysis, we will use daylight duration as the main instrumental variable in the

following sections. For a similar reasoning and for brevity purposes, we will focus on daily daylight duration in the remainder of this section.[13]

4.3 Heterogeneity

We next explore the heterogeneity in how individuals adjust their time in response to daily daylight duration variations with respect to: (i) child gender (i.e., male versus female), (ii) child age (young versus old, identified relative to the median age of all individuals in the whole sample), (iii) whether the diary was completed on weekends/holidays versus weekdays, and (iv) whether the child's mother was employed versus unemployed.[14] We implement this heterogeneity analysis by separately running the regression equation (1) on two sub-samples of individuals identified by each of the above characteristics. For maternal employment status, sub-groups are defined using the value identified at its first appearance in the sample to address a concern that the children's time allocation or daylight duration may affect the way that we assign them to each sub-group.

Sub-group estimates, reported in Figure 1, show the differential impacts of daily daylight duration for some sub-group characteristics and outcomes. Particularly, the effects of daylight duration on study children's sleep duration tend to be greater for females, older study children, on weekends, or for children of employed mothers, because the estimates are always more negative (i.e., children are sleeping less on days with a longer daylight duration) or typically more statistically significant for them. Moreover, the sub-population estimates on non-sleep variables suggest some potential mechanisms for these heterogenous daylight duration impacts on sleep duration. For instance, the greater reduction in sleep duration for females is mainly explained by the fact that, when compared to males, females spend more time on physical activities but less time on school activities as daylight duration increases.

Likewise, the proportionally larger effect that increasing daylight duration has specifically on sleep duration for older individuals, is consistent with the finding that increasing daylight duration has a smaller effect on the time they spend on selected non-sleep activities such as personal care, physical

[13] Unreported results on daily sunrise and sunset time lead to similar conclusions and the results are available upon requests. Online Appendix C shows that the estimated relationship between daylight duration and children's time allocation is robust to various sensitivity checks.

[14] Unemployed sub-group includes individuals classified as "unemployed" or "not in the labour force".

and media activities for them. This age difference in the daily daylight duration impact on sleep duration corresponds well with the differential daily daylight duration effect on sleep onset time or wakeup time. In particular, older individuals adjust to longer daylight duration by waking up earlier (i.e., a one-hour increase in daylight duration decreases wake-up time by 6 minutes) without changing their sleep onset time. Younger individuals, by contrast, respond mainly by starting their sleep much later (i.e., a one-hour increase in daylight duration increases their sleep onset time by 7 minutes). Our finding of a greater daylight duration effect on sleep duration for older individuals is consistent with the premise that older individuals are more likely to be affected by social constraints, such as school schedules (Hamermesh *et al.* 2008), and thus less able to compensate an earlier wakeup time with an earlier bedtime.

Figure 1 further indicates that the differential daylight duration effects on time allocated to non-sleep activities help to explain the more apparent impact of increasing daylight duration on sleep duration on weekends. Specifically, increasing daylight duration has a statistically significant effect on study children's time allocations to personal care, school and chores activities on weekdays only. Moreover, the impact of daylight duration in increasing physically active time on weekends is twice as much as that on weekdays (i.e., a one-hour increase in daylight duration increases physically active time by 3 and 8 minutes per day on weekdays and weekends, respectively). Figure 1 also shows that individuals adjust to longer daylight duration by going to sleep later on weekdays but by waking up earlier on weekends. Our finding of a more pronounced impact of daylight duration on sleep duration undertaken on weekends is in line with that in previous studies where children's time allocations to physical and media activities are more responsive to weather conditions on weekends (Nguyen *et al.* 2021a; Nguyen *et al.* 2021b). Like the previous findings, our finding is consistent with the view that individuals are more flexible on weekends, probabably because they are less socially constrained by their own school schedules or their parent's work commitments on weekends.

Sub-population results by maternal work status indicate that the daylight duration impact on sleep duration is more prominent for children of employed mothers because the estimate is statistically significant (at 1% level) for them only. This differential impact is consistent with a pattern that only children of employed mothers adjust to longer daylight duration partly by going to sleep later and waking up earlier. Our finding coupled with prior evidence showing that solar cycles affect sleep duration of employed adults only (Giuntella *et al.* 2017) suggest that employment status of parents

influences the way that both parents and their offspring adjust their sleep patterns in response to daily solar cycle changes.

Our results further reveal that children of employed mothers also spend signficantly more time at schools on days with longer daylight duration. This finding when observed with a pattern that, as compared to children of unemployed mothers, those of employed mothers spend less time on sleep (30 minutes per day, as can be seen from mean figures reported below the bars in Figure 1) but more time at schools (41 minutes per day) suggest the following. Work arrangements of mothers affect how their children allocate their time during the day as well as how the children adjust their time in response to daily solar cycle variations.

5. Impact of sleep duration on child health and development

5.1 Empirical models

We now empirically investigate the effect of sleep duration on child developmental outcomes using the following equation:

$$Y_{it} = \lambda + \rho D_{it} + X_{it}\varphi + \delta_i + \varepsilon_{it} \qquad (2)$$

where Y_{it} is a child development outcome and D_{it} is child sleep duration (measured in hours per day). X_{it} is a vector of controls as in Equation (1). δ_i is an individual fixed effect and ε_{it} is an error term. λ, ρ and φ are parameters to be estimated. The coefficient of interest is ρ which gauges the effect of sleep duration on a child development outcome.

Equation (2) which controls for individual time-invariant factors would produce a more accurate estimate of sleep duration than a pooled regression model which does not control for such factors. However, it cannot control for time-variant factors or address the reverse causality issue, leaving a causal interpretation of FE estimate uncertain. We tackle these issues as previous studies have (Giuntella *et al.* 2017; Gibson & Shrader 2018; Kajitani 2021) by employing an instrumental variable for sleep duration in Equation (2). In particular, we employ an auxiliary equation similar to Equation (1) in which we use sleep duration (D_{it}) as the dependent variable.

A successful application of an IV model relies on an ability to find at least one valid instrument which satisfies two conditions: (i) it is strongly correlated with sleep duration and (ii) it does not covary with

other child development determinants (Wooldridge 2010). Following prior studies (Giuntella *et al.* 2017; Gibson & Shrader 2018; Kajitani 2021) and building on the results in Section 0 which show that sleep duration is most sensitive to daily daylight duration, we propose to use daily daylight duration as an instrument.[15] Unlike previous studies which mostly use cross-sectional data and hence cannot control for individual heterogeneity, we augment this IV approach with an individual fixed effects (FE) regression model. Our FE-IV model thus effectively controls for time-invariant factors which may be associated with both the instrument and child development outcome.

Our identification strategy exploits variations in daily daylight duration on pre-determined TUD dates[16] for the same individual. This identification strategy eases the key concern that seasonal factors correlate with both daylight duration and developmental outcomes when modelling a solar cycle - based instrument (Gibson & Shrader 2018). To further alleviate this concern, our FE-IV model still controls for quarter dummies.[17] In Section **Error! Reference source not found.**, we further check the robustness of our results to the second condition for a strong instrument by additionally controlling for various time-variant observable factors which potentially covary with the daily daylight duration and child development outcomes.

The unit of analysis in this section is diary level and we do not distinguish whether a diary is recorded on weekends or weekdays to have a sufficiently large sample to provide reliable estimates. We estimate the FE-IV model using a Two-Stage Least-Squares (2SLS) method. As have been done with

[15] Our instrument is closest to that in Gibson and Shrader (2018) who use daily sunset time recorded on the diary date as an instrument. Other studies employ yearly average sunset time at a local level as an instrument (Giuntella *et al.* 2017; Kajitani 2021). Appendix Figure A5 and Appendix Table A1 show substantial variations in daily daylight duration between and within individuals for us to employ a FE model.

[16] Particularly, TUD dates were pre-selected by the interviewers to obtain a random distribution of weekdays and a random distribution of weekend days (Corey *et al.* 2014). Moreover, an attempt has been made to keep the survey duration between two adjacent waves within a 24 month period (Mohal *et al.* 2021), easing a concern that survey dates and hence TUD dates were solely determined by the respondent. In line with this survey design, Appendix Figure A6 shows that the median duration between two adjacent survey waves is 24.67 months. Because our empirical strategy exploits variations in daily solar cycles recorded on the pre-determined diary dates across the same individuals over time, there is not sufficient variation in daily solar cycles in the data for us to control for a temporal level lower than a quarter level (e.g., by controlling for month dummies).

[17] LSAC was implemented mostly in non-summer months, which do not include school summer holidays or Christmas/New Year holidays, to maximize the response rate (Mohal *et al.* 2021). Consistent with this survey design, Appendix Figure A7 shows that about 87% of TUDs were completed between April and September. This survey period does not include summer months in Australia and exhibits shorter daylight duration than the rest of year. Appendix Figure A8 exhibits that daylight duration follows a yearly cycle pattern, suggesting a need to control for other seasonal factors potentially covarying with both daylight duration and child development.

Equation (1), in this section, standard errors are clustered at the individual level to address potential serial correlations.

As with other IV studies, the IV estimates in this paper capture a Local Average Treatment Effect (LATE) of sleep duration on child development (Imbens & Angrist 1994). Specifically, the LATE is applicable to individuals who adjust their sleep duration in response to the change in local daily daylight duration ("compliers"). Our instrument affects all individuals in the data, as can be seen in Appendix Figure A2 which visually shows that shorter daylight durations increase sleep duration for almost all individuals along the whole distribution. Section 0 additionally indicates females, older individuals or children of employed mothers are more likely to be "compliers" since their sleep duration is more responsive to daily daylight duration variations (Angrist & Pischke 2008).

5.2 Child health and development outcomes

We consider the impact of sleep duration on five sets of child development outcomes. The first outcome set measures general development in children and adolescents aged 2 to 18 years and is derived from the parent-report version of the Pediatric Quality of Life Inventory (PedsQL) (Varni *et al.* 2001). This set includes three sub-scales describing Social, Emotional, and Physical development and an Overall PedsQL scale.[18] For ease of interpretation, we rescale all PedsQL measures so that a higher score indicates a more desirable trait. Moreover, for a similar reasoning, we standardize each of these outcomes to have a zero mean and a unit standard deviation.

The second development set describes child behavioural and socio-emotional development, constructed from the corresponding parent's responses to the Strengths and Difficulties Questionnaire (SDQ). This set includes an overall SDQ summary scale and five sub-scales: pro-social behaviour (hereafter called Pro-sociality), hyperactivity and inattention (Hyperactivity), emotional

[18] Particularly, the corresponding parent was asked a series of questions, asking "In the past one month how often would you say this child has had a problem with…". The "Social development" sub-scale is constructed from responses to problems socialising with other kids, with other children not playing with study child, getting teased, unable to do what other children can, or problems keeping up with other children. The "Emotional development" sub-scale is calculated from responses to problems feeling afraid or scared, feeling sad, feeling angry, sleeping, and with worrying. The "Physical development" sub-scale is constructed from responses to problems with walking, running, sports or exercise, heavy lifting, bathing, helping to pick up toys, hurts or aches, or low energy levels. Responses are recorded as 1 Never; 2 Almost never; 3 Sometimes; 4 Often; 5 Almost always. See Appendix Table A2 for timeline of TUDs and developmental outcomes in the LSAC.

symptoms (Emotional), conduct problems (Conduct), and peer-relationship problems (Peer). As has been done with the PedsQL measures, we rescale the SDQ measures so that higher SDQ scores indicate more desirable outcomes. We also standardize all SDQ - based measures.

The third outcome set includes four interviewer-administered anthropometric measures. The first measure is standardized gender- and age-adjusted Body Mass Index (BMI) scores, which are calculated using child height, weight and ages (in months) and the World Health Organization (WHO) growth reference chart (Vidmar *et al.* 2013). To capture the potential differential impact of sleep duration on individuals at two ends of the standardized BMI scores, we additionally use two binary indicators describing if the individual is classified as being underweight or overweight. The last anthropometric measure is the waist-for-height ratio.

The fourth set consists of six measures describing the individual's health. The first three of these include indicators describing if the individual (i) has "excellent health",[19] (ii) has "any ongoing condition",[20] or (iii) currently uses "prescribed medicine".[21] For the remaining indicators we also consider the impact of sleep on three health expenditure measures which are derived from linked LSAC-administrative Medicare data. Medicare data record all Australian Government subsidies and out-of-pocket payments for medical services (from the Medicare Benefit Scheme (MBS)) and pharmaceuticals (from the Pharmaceutical Benefit Scheme (PBS)) under Australia's universal and compulsory Medicare scheme. About 97% of LSAC children are linked to Medicare data and, for them, we have information on health expenditures from birth until March 2019 (Mohal *et al.* 2021). We measure yearly health expenditures from MBS and PBS separately along with the sum of these two expenditure types.

The fifth outcome set captures child cognitive skills which are constructed using scores from Matrix Reasoning (MR) and the National Assessment Program – Literacy and Numeracy (NAPLAN) tests. The

[19] This binary variable takes the value of one if the corresponding parent responses "Excellent" to a question asking: "In general, how would you say child current's health is: 1 Excellent; 2 Very good; 3 Good; 4 Fair; 5 Poor", and zero otherwise.
[20] This binary measure takes the value of one if the corresponding parent responses "Yes" to the question "Does study child have any of these ongoing conditions?", and zero otherwise. The list of ongoing conditions varies by waves, preventing us from using a particular condition as an outcome.
[21] This binary variable takes the value of one if the corresponding parent responses "Yes" to the question "Does child currently need or use medicine prescribed by a doctor, other than vitamins?", and zero otherwise.

MR is a subtest of the Weschler Intelligence Scale to measure a child's non-verbal visuospatial ability. MR were administered by the interviewer when children were 6 to 11 years (Mohal *et al.* 2021). The NAPLAN test is administered to all Australian students in grades 3, 5, 7 and 9 in the five domains of reading, writing, spelling, grammar and numeracy. The NAPLAN test results were made available via data linkage with the LSAC data (Daraganova *et al.* 2013). We also standardize each of these cognitive outcomes to facilitate interpretation of the results.

5.3 Descriptive analysis

Table 2 reports summary statistics for the main explanatory variables and outcomes by sleep duration sub-groups. It shows that individuals who sleep longer (i.e., individuals with sleep duration ≥ median) tend to be younger, female, born to mothers who have lower education or mothers who were born in Australia or born overseas in an English-Speaking-Background (ESB) country, to have fewer siblings or to live in two-parent families. Table 2 also indicates that individuals who sleep longer do better in some general development or behavioural outcomes as measured by PedsQL (all three sub-scales) or SDQ (two sub-scales: Emotional and Peer). By contrast, children who sleep longer tend to have lower scores for other behavioural outcomes such as Pro-sociality, Hyperactivity, Conduct or SDQ Overall. Moreover, individuals with a longer sleep duration have lower BMI, a lower probability of being overweight or higher waist-to-height ratios. They are more likely to have better self-reported health conditions or lower health-related expenditures. Contrarily, individuals who sleep longer have lower test scores in all cognitive domains. However, it is important to note that this simple comparison does not account for observable or unobservable characteristics, and reverse causality. We address these issues directly in the following sections.

5.4 Main results

FE and FE-IV results are reported in Tables 3, 4 and 5.[22] FE results for general development and behavioural outcomes, reported in odd columns of Table 3, show a statistically significant (at least at

[22] Results from the first and second stage regressions are reported in Appendix Table A6 and Appendix Table A7, correspondingly. The results are largely as expected and in line with that in previous studies (Le & Nguyen 2017, 2018). For instance, child ages are strongly associated with various development outcomes. Moreover, children in two-parent families have better developmental outcomes. However, there is little evidence suggesting that child development outcomes vary by seasonal factors, as measured by quarter or day-of-week dummies. We also report results from pooled OLS (POLS) and IV regressions where we do not control for individual fixed effects in Appendix Table A8, Appendix Table A9 and Appendix Table A10. As compared to FE estimates, POLS estimates

5% level) and positive estimate of sleep duration on Emotional development, PedsQL Overall, Emotional symptoms, Conduct and SDQ Overall. These significant estimates suggest that sleeping longer benefits such developmental outcomes. Similarly, the statistically significant FE estimates of sleep duration on health-related outcomes, reported in odd columns of Table 4, suggest sleeping longer offers some health benefits. Specifically, health benefits include a reduction in BMI score, a reduced risk of being overweight or having any health condition, and a higher probability of having excellent health. However, apart from a marginally statistically significant (at 10% level) and positive estimate of sleep duration on Grammar, FE estimates are statistically insignificant for all considered cognitive outcomes (see odd columns in Table 5), suggesting that sleeping more may not statistically significantly improve cognitive skills in children and adolescents.

FE-IV estimates, reported in even columns of Tables 3 to 5, present four main findings. First, the weak identification tests from FE-IV regressions produce large Kleibergen-Paap statistics (the lowest F statistic is 22, as for Social development) that compare favourably to the statistics reported in Stock and Yogo (2005). These test statistics thus reject the hypothesis of a weak instrument for all regressions. Second, applying a FE-IV estimator substantially changes the results for some developmental outcomes. Specifically, the FE-IV estimator substantially increases the size of the sleep duration estimate on Emotional development but reduces the statistical significance to 10% level. Moreover, the FE-IV estimator turns the estimate of sleep duration on Physical development from statistically insignificant to statistically significant at 10% level. Likewise, the FE-IV estimator noticeably increases the size of sleep duration impact on PedsQL Overall while preserving its statistical significance at 5% level. Thus, FE-IV results indicate a much more pronounced benefit (in terms of the statistical significance or magnitude) of sleeping longer on these three general development outcomes than previously observed with the FE results.

The FE-IV estimator changes the sleep duration estimates on BMI and overweight from negative to positive, without changing their statistical significance level. The FE-IV results therefore indicate that sleeping more increases BMI scores, mainly by increasing the probability of being overweight, in

are more pronounced in terms of the statistical significance or magnitude. Moreover, while the POLS estimates suggest a highly statistically significant and negative association between sleep duration and all cognitive outcomes, the FE estimates indicate a statistically insignificant relationship. As compared to IV estimates, FE-IV estimates tend to be more statistically significant for some outcomes such as PedsQL Overall, BMI or overweight.

children and adolescents. Consistent with the positive impact of sleep on these BMI-related measures, the FE-IV estimate shows that sleeping longer also marginally statistically (at 10% level) increases MBS expenditures. Lastly, the FE-IV estimator substantially increases the size of sleep duration estimate on Spelling and turns the estimate to statistically significant at 5% level (see Table 5). The FE-IV estimate therefore suggests that sleeping longer improves Spelling scores.

Third, the changes in the magnitude and statistical significance level in the estimates of sleep duration on the above-mentioned development outcomes are consistent with results from a Hausman test which indicate that sleep duration is endogenous when modelling these outcomes (see Hausman test statistics reported in Tables 3 to 5). The results thus demonstrate that failing to adequately account for the endogeneity of sleep duration would lead to an inaccurate picture of the impact of sleep duration on these outcomes.

Fourth, FE-IV estimates of sleep duration on other development outcomes are not statistically significant at any conventional level. These statistically insignificant estimates are in line with the results from a Hausman test which suggest that we can model sleep duration and these outcomes independently. Therefore, the results from two Hausman-styled tests[23] suggest that a FE model would be suitable and hence preferred to identify the causal effects of sleep duration on these outcomes.

Overall, the preferred results from this section show that sleeping longer improves selected general developmental and behavioural outcomes, including Emotional development, Physical development, PedsQL Overall, Emotional symptoms, Conduct, and SDQ Overall. Sleeping more is also found to increase the probability of having excellent health or decrease the likelihood of having any ongoing health condition. By contrast, sleeping longer statistically significantly increases BMI scores, mainly by increasing the risk of being overweight, in children and adolescents. This causal evidence of sleep duration on BMI scores helps verify an unproven hypothesis that "sleep duration seems to influence weight gain in children" (Felső *et al.* 2017).

In line with the previous finding on children from the developing world (Jagnani 2022), our results also indicate some cognitive benefits of sleeping longer. However, the estimates, when statistically

[23] Unreported statistics from a Hausman test suggest that the FE model is preferred to the pooled OLS model for all outcomes.

significant, appear quantitatively small in terms of both statistical significance (i.e., the estimates are statistically significant at 5 and 10 % level for Spelling and Grammar, respectively) and magnitude (e.g., a one-hour increase in sleep duration per day is associated with an increase of 0.11 (0.004) standard deviations in Spelling (Grammar) test score). Our finding of a null or relatively small positive impact of sleep duration on cognitive skills is consistent with previous findings indicating that educational activities are the most productive input for cognitive development (Fiorini & Keane 2014; Nguyen *et al.* 2020). These findings are in line the premise that, given the limit of 24 hours per day, to increase sleep duration, individuals must reduce the time spent on other activities, especially educational activities.

6. Robustness checks and additional results

6.1 Robustness checks

This section checks whether our main findings are robust to: (i) different instruments, (ii) the exclusion or inclusion of some potentially important time-variant variables, (iii) the inclusion of local weather conditions, and (iv) a reduced-form regression approach. These checks address concerns about the validity of the instrument so they are applied to the FE-IV model only.

We first experiment with using daily sunrise time or daily sunset time in place of daily daylight duration as a separate instrument in the original FE-IV regression framework. We obtain largely similar results (reported in Panel B1 of Appendix Table A11) when employing daily sunrise time as an instrument. One notable difference is that the estimate of sleep duration on the waist-to-height ratio is (still) positive but statistically significant at 5% level. Thus, the sleep duration estimates on BMI- and waist-based scores all indicate that sleeping longer increases the risk of being overweight. We also arrive at a broadly similar conclusion, although at a slightly lower precision level, when instrumenting sleep duration by daily sunset time (see Panel B2). This decrease in precision is consistent with the fact that children's sleep duration is least responsive to daily sunset time, resulting in the lowest F statistics (see F statistics reported at the bottom of each panel).

The second set of robustness checks consists of excluding or including some important time-variant variables. We start by excluding all individual and household level time-variant explanatory variables other than the child age-related variables and find our results (reported in Panel C) are largely similar to the baseline results (reproduced in Panel A). As discussed in Section 0, the primary threat to exclusion restriction would be that time-variant unobserved shocks are systematically associated with

child sleep duration and development outcomes. Although it is challenging, if not impossible, to rule out the existence of confounding factors that would influence our estimates, we provide evidence that our estimates are insensitive to the inclusion of an extensive set of such time-variant variables. In particular, we additionally control for each of some grouped activities which have been shown to be affected by daily daylight duration in Section 0, and some of them may also influence the child development (Fiorini & Keane 2014; Nguyen *et al.* 2022a). These include the daily time allocated to personal care, school, physical and media activities and results are reported in Panel D1, D2, D3 and D4 of Appendix Table A11, respectively. For a similar reasoning, we separately control for the corresponding parent's general health (results are reported in Panel D5), mental health (D6), and employment status (D7) or household income (D8).

Third, we additionally control for weather conditions recorded on the diary date (Panel E1) or cumulative weather conditions in the 365 days before the survey date (Panel E2).[24] The results show our findings are insensitive to the inclusion of these weather variables. Fourth, more evidence demonstrating the credibility of our findings is that the reduced form effects of daily daylight duration on child development outcomes (Panel F) display similar patterns as the 2SLS estimates.

6.2 Non-linear impact of sleep duration

Medical literature often documents a non-monotonic association between sleep duration and mortality (Cappuccio *et al.* 2010; Svensson *et al.* 2021) or BMI (Cappuccio *et al.* 2008). While our empirical model is not ideal to explore the potentially non-linear causal effect of sleep duration on child development,[25] in this section, we attempt to explore this possibility in three ways. First, we introduce the endogenous sleep duration variable in a quadratic form in Equation (2) and apply a FE

[24] As has been done in Section 0, daily weather conditions are measured by daily maximum temperature (and its square) and precipitation. To capture potential cumulative local weather exposure, following previous studies (Dell *et al.* 2014; Graff Zivin *et al.* 2018), we include the number of days with daily maximum temperature exceeding some thresholds and number of rainy days in the 365 days prior to the survey date.

[25] One popular method to explore this possibility is to include sleep duration in a quadratic form in Equation (2). However, we cannot apply an IV approach to this modified model because of a lack of appropriate instruments to identify it. Specifically, to employ an IV approach to this modified model, we need at least two instruments, one for each of two potentially endogenous variables (i.e., sleep duration and its square). Theoretically, as suggested by Wooldridge (2010), this modified model can be identified by including the instrument (i.e., daylight duration in this case) in a quadratic form. This approach, however, does not work in practice because estimates of daylight duration and its square are not statistically significant in the first-stage regression. Probably due to the same unresolved identification issue, previous IV studies have not succeeded in drawing a non-linear causal impact of sleep duration either (Giuntella *et al*. 2017; Gibson & Shrader 2018).

regression method to estimate this modified model. As discussed earlier, a causal interpretation of the results obtained from this modified FE model requires a rather strong assumption that all individual time-variant unobserved characteristics are not simultaneously associated with sleep duration and child development. While this assumption cannot be formally tested in this case, the test results from the baseline FE-IV regressions provide some support for this approach because we found little evidence against this assumption for most outcomes (i.e., the p value of the Hausman test for exogeneity is greater than 0.1 in 18 out of 26 outcomes).

FE results, reported in Appendix Table A12, suggest no evidence of a non-linear relationship between sleep duration and most of the child development outcomes considered because estimates of the quadratic term of sleep duration are statistically insignificant in almost all cases. There are two exceptions. First, the marginally statistically significant (at 10% level) and positive estimate of sleep duration variable and the statistically significant (at 5% level) and negative estimate of its quadratic term on Physical development suggests an inverted U-shaped relationship between sleep duration and Physical development. Numerically, the results suggest that children's physical development first increases with sleep duration, before starting to fall after 8 hours per day. By contrast, the statistically significant (at 1% level) and negative estimate of sleep duration and the statistically significant (at 1% level) estimate of its squared term on MBS expenditures indicate a U-shaped association between sleep duration and MBS expenditures. Specifically, children's MBS expenditures arrive at their minimum value when sleep duration reaches 11.5 hours per day, before increasing afterwards.

Second, to further explore the potential non-linear impact of sleep duration in a more flexible way, we categorize the daily sleep duration variable in the FE regression model. Specifically, we set the 10-11 sleep hour band, which includes the median of 10.5 daily sleep hours of all children in our sample, as the base, resulting in all other sleep duration band estimates being compared to the estimate of this sleep duration band.

The results, reported in Appendix Figure A9, suggest a non-linear relationship between sleep duration and selected outcomes.[26] For instance, the negative and statistically significant (at least at 5% level) estimates of the lowest sleep duration band (i.e., <8 hours) on Emotional development, PedsQL

[26] As discussed above, FE results in this exercise may not be interpreted as causal. Furthermore, results for some outcomes or sleep hour bands are statistically under-powered, possibly because of the small sample sizes.

Overall, SDQ Emotional, SDQ Overall, and Excellent health indicator show that, as compared with individuals sleeping from 10 up to 11 hours per day, those sleeping less than 8 hours daily have worse developmental outcomes in these domains. The statistically significant but opposite estimates of the highest sleep hour band on Emotional development and SDQ Peer indicate that, as compared to individuals with 10-11 sleep hours per day, those sleeping 14 hours or more each day have a better outcome in Emotional development but worse in Peer. Moreover, the statistically significant and positive (negative) estimate of the 8-9 (<8) sleep hour band on BMI (Underweight) indicates weight gain associated with sleeping longer is mainly observed for individuals with these low sleep hours. Furthermore, the positive and statistically significant estimates of the two top sleep hour bands on Grammar suggest that individuals who sleep 13 hours or more per day have greater grammar scores than those with a shorter sleep duration. Thus, the results from this exercise tend to indicate that the previously identified effects of sleep duration on these selected outcomes might have been driven by individuals at the two tails of the sleep duration distribution.

Third, motivated by sleep deprivation literature (Cappuccio *et al.* 2010), we dichotomize the sleep duration variable, using various cut-off points with a 30-minute increment, and use each of these newly created dummy variables in place of the continuous sleep duration variable in the baseline FE-IV model. We still use daily daylight duration as the sole instrument in this modified FE-IV model. Because the instrument is only sufficiently statistically significantly (i.e., F statistic from the first stage regression >10) associated with sleep binary variables identified between a range from 10 to 12 hours, we apply this modified model to these selected sleep duration cut-offs. Comparing the estimates for individuals with different sleep duration cut-offs, e.g., individuals sleep at least 11 hours per day and those sleep at least 10.5 hours per day, may reveal evidence for whether sleep has a non-linear impact on child development.

Unreported results from this experiment show little evidence of non-linearity in the impact of sleep duration on almost all development outcomes considered because estimates of sleep duration cut-off variables are not statistically significant at any conventional level. Exceptions are noted and reported in Appendix Figure A10 for three outcomes: BMI, overweight and MBS expenditures. Specifically, estimates of sleep duration cut-offs on these outcomes are positive and statistically significant (at least at 10% level) over the whole cut-off points considered. Visually, the relationship between sleep duration cut-offs and each of these three outcomes follows a U-shaped pattern and lowest estimates are observed at the cut-off of 10.5 hours per day. The finding that weight gain and hence the risk of

being overweight are higher for individuals at the two ends of the sleep duration spectrum is consistent with an oft-observed pattern of an increased risk of obesity amongst short sleepers in children (Cappuccio *et al.* 2008).

Overall, the results from this sub-section show some evidence of a non-linear relationship between sleep duration and selected general development, behavioural and health-related outcomes. However, the results indicate little evidence of such a non-linear relationship for almost all cognitive outcomes. To this end, our finding of a linear relationship between sleep duration and selected cognitive skills is in line with that in an experimental study by Lo *et al.* (2016) who find cognitive performance of adolescents is nearly-linearly correlated with accumulated duration of sleepiness over time.

6.3 Heterogeneity

We study heterogeneous effects of sleep with respect to: (i) child gender (male versus female) and (ii) child age (young versus old, identified relative to the median age of all individuals in the pooled sample).[27] To do this, we run separate regressions by sub-groups distinguished by each of the above characteristics using a FE-IV model for all outcomes and report the results from this model if the exogeneity of sleep duration is rejected (i.e., when the p value of the Hausman test for exogeneity is equal or smaller than 0.1). When the exogeneity of sleep duration is not rejected, we report results from the FE estimator.

Sub-population results by gender and age (reported in Appendix Table A13 and Appendix Table A14, respectively) suggest that sleep duration appears to have some differential effects by gender and age. For example, the impacts on some general developmental and behavioural outcomes, including Emotional development, Physical development, PedsQL Overall, Emotional symptoms and SDQ Overall, are more pronounced for females or older individuals because the estimates of sleep duration are typically greater (i.e., more positive) or more statistically significant for them. Moreover, the *negative* and statistically significant (at 5% level) FE-IV estimate of sleep duration on Peer sub-scale

[27] We refrain from running separate regressions by other potentially important characters, such as maternal education level, mainly because we lack a statistical power, including a weak instrument issue, for some sub-groups or outcomes. Some findings in this section should be interpreted with caution because, for some sub-groups and outcomes, the instrument is relatively weak, probably because of the small sample sizes.

for females indicates that sleeping longer actually worsens this behavioural outcome for females only. By contrast, the sleep duration estimates on BMI and the probability of being overweight are positive and statistically significant (at 5% level) for males only, suggesting that the previously observed impacts of sleep duration on these BMI-based outcomes from the pooled sample are entirely driven by males.

7. Conclusion

This paper exploits variations in local daily daylight duration recorded on diary dates across the same individuals to assess the causal impacts of sleep duration on child development. Our results show that longer daylight duration statistically significantly reduces sleep duration in children and adolescents, partly by inducing them to go to sleep later and wake up earlier. Longer day lengths also decrease children's time allocations to personal care or media activities and increase the time they allocate to school or physical activities. We provide novel evidence that the effects of day length on sleep duration are greater for females, older individuals, children of employed mothers or on weekends.

Employing a fixed effects instrumental variables approach, we find that sleeping longer improves selected general developmental and behavioural outcomes, such as Emotional development, Physical development, Health related quality of life (i.e., PedsQL Overall), Emotional symptoms, Conduct and behavioural and emotional difficulties generally (SDQ Overall). Our results also reveal that sleeping more increases the probability of having excellent health or decreases the likelihood of having any ongoing condition. By contrast, sleeping longer statistically significantly increases BMI scores, mainly by increasing the risk of being overweight. Moreover, while the beneficial effects of sleeping longer on general and behavioural outcomes are more pronounced for females or older individuals, the impact on BMI is only observed for males. Furthermore, the results show statistically insignificant or a relatively small positive impact of sleeping more on cognitive development. We also uncover evidence of a non-linear relationship between sleep duration and selected general development, behavioural and health-related outcomes, suggesting a more pronounced impact of sleeping longer for individuals at the two ends of the sleep duration spectrum. Finally, we find the results are robust to a range of sensitivity checks.

The findings presented in this paper highlight the importance of addressing potential endogeneity of sleep duration when quantifying its impact on child developmental outcomes. The findings of substantial health and development benefits of sleeping longer from this study reinforce the need to

formulate policies to reduce sleep deprivation in young individuals, especially in females and adolescents who appear to benefit more. This paper also identifies undesirable effects of sleeping longer on some developmental outcomes, including increased BMI and a higher risk of being overweight for males, and these side effects should be considered when designing such policies.

The main objective of this paper is to provide evidence on the causal relationship between sleep duration and child development. With this said, it is beyond the scope of this paper to explore the precise mechanisms behind the estimated impacts. More and better research is needed to reveal potential underlying mechanisms. Moreover, our empirical model is not ideally suited to detect a non-linear causal impact of sleep duration on child development, causing some uncertainty around establishing an amount of sleep duration considered optimal for improving any given health or developmental outcome in young individuals. More studies, such as field experiments (Bessone *et al.* 2021), which have the power to find more definitive answers to this important question are necessary.

References

Angrist, J.D., Pischke, J.-S., 2008. Mostly harmless econometrics: An empiricist's companion. Princeton university press.

Becker, G.S., 1965. A Theory of the Allocation of Time. The Economic Journal 75, 493-517

Beebe, D.W., Field, J., Millller, M.M., Miller, L.E., LeBlond, E., 2017. Impact of Multi-Night Experimentally Induced Short Sleep on Adolescent Performance in a Simulated Classroom. Sleep 40, zsw035

Bessone, P., Rao, G., Schilbach, F., Schofield, H., Toma, M., 2021. The Economic Consequences of Increasing Sleep among the Urban Poor. The Quarterly Journal of Economics 136, 1887–1941

Biddle, J.E., Hamermesh, D.S., 1990. Sleep and the Allocation of Time. Journal of Political Economy 98, 922-943

Cappuccio, F.P., D'Elia, L., Strazzullo, P., Miller, M.A., 2010. Sleep duration and all-cause mortality: a systematic review and meta-analysis of prospective studies. Sleep 33, 585

Cappuccio, F.P., Taggart, F.M., Kandala, N.-B., Currie, A., Peile, E., Stranges, S., Miller, M.A., 2008. Meta-Analysis of Short Sleep Duration and Obesity in Children and Adults. Sleep 31, 619-626

Carrell, S.E., Maghakian, T., West, J.E., 2011. A's from Zzzz's? The Causal Effect of School Start Time on the Academic Achievement of Adolescents. American Economic Journal: Economic Policy 3, 62-81

Chaput, J.-P., Gray, C.E., Poitras, V.J., Carson, V., Gruber, R., Birken, C.S., . . . Tremblay, M.S., 2017. Systematic review of the relationships between sleep duration and health indicators in the early years (0–4 years). BMC Public Health 17, 855

Chaput, J.-P., Gray, C.E., Poitras, V.J., Carson, V., Gruber, R., Olds, T., . . . Tremblay, M.S., 2016. Systematic review of the relationships between sleep duration and health indicators in school-aged children and youth. Applied Physiology, Nutrition, and Metabolism 41, S266-S282

Corey, J., Gallagher, J., Davis, E., Marquardt, M., 2014. The Times of Their Lives: Collecting time use data from children in the Longitudinal Study of Australian Children (LSAC). In: LSAC Technical Paper No. 13. Australian Government Department of Social Services, Canberra

Costa-Font, J., Fleche, S., 2020. Child Sleep and Mother Labour Market Outcomes. Journal of Health Economics 69, 102258

Daraganova, G., Edwards, B., Sipthorp, M., 2013. Using National Assessment Program—Literacy and Numeracy (NAPLAN) data in the Longitudinal Study of Australian Children (LSAC). In: LSAC Technical Paper No. 8, Australian Institute of Family Studies

Dell, M., Jones, B.F., Olken, B.A., 2014. What Do We Learn from the Weather? The New Climate–Economy Literature. Journal of Economic Literature 52, 740-798

Dewald, J.F., Meijer, A.M., Oort, F.J., Kerkhof, G.A., Bögels, S.M., 2010. The influence of sleep quality, sleep duration and sleepiness on school performance in children and adolescents: A meta-analytic review. Sleep Medicine Reviews 14, 179-189

Edwards, F., 2012. Early to rise? The effect of daily start times on academic performance. Economics of Education Review 31, 970-983

Felső, R., Lohner, S., Hollódy, K., Erhardt, É., Molnár, D., 2017. Relationship between sleep duration and childhood obesity: Systematic review including the potential underlying mechanisms. Nutrition, Metabolism and Cardiovascular Diseases 27, 751-761

Fiorini, M., Keane, M.P., 2014. How the Allocation of Children's Time Affects Cognitive and Non-Cognitive Development. Journal of Labor Economics 3, 787-836

Frazis, H., Stewart, J., 2012. How to Think about Time-Use Data: What Inferences Can We Make about Long- and Short-Run Time Use from Time Diaries? Annals of Economics and Statistics, 231-245

Gentzkow, M., Shapiro, J.M., 2008. Preschool Television Viewing and Adolescent Test Scores: Historical Evidence from the Coleman Study. The Quarterly Journal of Economics 123, 279-323

Gibson, M., Shrader, J., 2018. Time Use and Labor Productivity: The Returns to Sleep. The Review of Economics and Statistics 100, 783-798

Giuntella, O., Han, W., Mazzonna, F., 2017. Circadian Rhythms, Sleep, and Cognitive Skills: Evidence From an Unsleeping Giant. Demography 54, 1715-1742

Giuntella, O., Mazzonna, F., 2019. Sunset time and the economic effects of social jetlag: evidence from US time zone borders. Journal of Health Economics 65, 210-226

Graff Zivin, J.S., Hsiang, S.M., Neidell, M.J., 2018. Temperature and Human Capital in the Short and Long Run. Journal of the Association of Environmental and Resource Economists 5, 77-105

Grossman, M., 1972. The Demand for Health: A Theoretical and Empirical Investigation. Columbia University Press for National Bureau of Economic Research Books, New York.

Hamermesh, D.S., Myers, C.K., Pocock, M.L., 2008. Cues for timing and coordination: latitude, letterman, and longitude. Journal of Labor Economics 26, 223-246

Harrison, Y., 2013. The impact of daylight saving time on sleep and related behaviours. Sleep Medicine Reviews 17, 285-292

Heissel, J., Norris, S., 2018. Rise and Shine: The Effect of School Start Times on Academic Performance from Childhood through Puberty. Journal of Human Resources 53, 957-992

Hirshkowitz, M., Whiton, K., Albert, S.M., Alessi, C., Bruni, O., DonCarlos, L., . . . Adams Hillard, P.J., 2015. National Sleep Foundation's sleep time duration recommendations: methodology and results summary. Sleep Health 1, 40-43

Holbein, J.B., Schafer, J.P., Dickinson, D.L., 2019. Insufficient sleep reduces voting and other prosocial behaviours. Nature Human Behaviour 3, 492-500

Imbens, G.W., Angrist, J.D., 1994. Identification and Estimation of Local Average Treatment Effects. Econometrica 62, 467-475

Jagnani, M., 2022. Children's Sleep and Human Capital Production. The Review of Economics and Statistics forthcoming

Jin, L., Ziebarth, N.R., 2020. Sleep, health, and human capital: Evidence from daylight saving time. Journal of Economic Behavior & Organization 170, 174-192

Kajitani, S., 2021. The return of sleep. Economics & Human Biology 41, 100986

Le, H.T., Nguyen, H.T., 2017. Parental health and children's cognitive and noncognitive development: New evidence from the longitudinal survey of Australian children. Health Economics 26, 1767–1788

Le, H.T., Nguyen, H.T., 2018. The Impact of Maternal Mental Health Shocks on Child Health: Estimates from Fixed Effects Instrumental Variables Models for two Cohorts of Australian Children. American Journal of Health Economics 4, 185-225

Lo, J.C., Ong, J.L., Leong, R.L.F., Gooley, J.J., Chee, M.W.L., 2016. Cognitive Performance, Sleepiness, and Mood in Partially Sleep Deprived Adolescents: The Need for Sleep Study. Sleep 39, 687-698

Matricciani, L., Paquet, C., Galland, B., Short, M., Olds, T., 2019. Children's sleep and health: A meta-review. Sleep Medicine Reviews 46, 136-150

Mattingly, S.M., Grover, T., Martinez, G.J., Aledavood, T., Robles-Granda, P., Nies, K., . . . Mark, G., 2021. The effects of seasons and weather on sleep patterns measured through longitudinal multimodal sensing. NPJ digital medicine 4, 1-15

Meeus, J.H., 1999. Astronomical algorithms. Willmann-Bell, Incorporated, Richmond, VA.

Minges, K.E., Redeker, N.S., 2016. Delayed school start times and adolescent sleep: A systematic review of the experimental evidence. Sleep Medicine Reviews 28, 86-95

Mohal, J., Lansangan, C., Gasser, C., Taylor, T., Renda, J., Jessup, K., Daraganova, G., 2021. Growing Up in Australia: The Longitudinal Study of Australian Children – Data User Guide, Release 9C1, June 2021. Australian Institute of Family Studies (Ed.), Melbourne

Nguyen, H.T., Brinkman, S., Le, H.T., Zubrick, S.R., Mitrou, F., 2022a. Gender differences in time allocation contribute to differences in developmental outcomes in children and adolescents. Economics of Education Review 89, 102270

Nguyen, H.T., Christian, H., Le, H.T., Connelly, L., Zubrick, S.R., Mitrou, F., 2021a. The impact of weather on time allocation to physical activity and sleep of child-parent dyads. Global Labor Organization (GLO) Discussion Paper No. 886

Nguyen, H.T., Christian, H., Le, H.T., Connelly, L., Zubrick, S.R., Mitrou, F., 2022b. Causal impact of physical activity on child health and development. Global Labor Organization (GLO) Discussion Paper No. 1081

Nguyen, H.T., Connelly, L., Le, H.T., Mitrou, F., Taylor, C., Zubrick, S., 2020. Ethnicity differentials in academic achievements: The role of time investments. Journal of Population Economics 33, 1381-1418

Nguyen, H.T., Le, H.T., Connelly, L.B., 2021b. Weather and children's time allocation. Health Economics 30, 1559-1579

Nieto, A., Suhrcke, M., 2021. The effect of TV viewing on children's obesity risk and mental well-being: Evidence from the UK digital switchover. Journal of Health Economics 80, 102543

Ohayon, M.M., Carskadon, M.A., Guilleminault, C., Vitiello, M.V., 2004. Meta-Analysis of Quantitative Sleep Parameters From Childhood to Old Age in Healthy Individuals: Developing Normative Sleep Values Across the Human Lifespan. Sleep 27, 1255-1273

Paruthi, S., Brooks, L.J., D'Ambrosio, C., Hall, W.A., Kotagal, S., Lloyd, R.M., . . . Wise, M.S., 2016. Recommended Amount of Sleep for Pediatric Populations: A Consensus Statement of the American Academy of Sleep Medicine. Journal of Clinical Sleep Medicine 12, 785-786

Reppert, S.M., Weaver, D.R., 2002. Coordination of circadian timing in mammals. Nature 418, 935-941

Roenneberg, T., Kumar, C.J., Merrow, M., 2007. The human circadian clock entrains to sun time. Current Biology 17, R44-R45

Schlieber, M., Han, J., 2021. The Role of Sleep in Young Children's Development: A Review. The Journal of Genetic Psychology 182, 205-217

Smith, A.C., 2016. Spring Forward at Your Own Risk: Daylight Saving Time and Fatal Vehicle Crashes. American Economic Journal: Applied Economics 8, 65-91

Stock, J.H., Yogo, M., 2005. Testing for Weak Instruments in Linear IV Regression. In: Andrews DWK (ed.) Identification and Inference for Econometric Models. Identification and Inference for Econometric Models. Cambridge University Press, New York, pp. 80-108.

Svensson, T., Saito, E., Svensson, A.K., Melander, O., Orho-Melander, M., Mimura, M., . . . Inoue, M., 2021. Association of Sleep Duration With All- and Major-Cause Mortality Among Adults in Japan, China, Singapore, and Korea. JAMA Network Open 4, e2122837-e2122837

Taras, H., Potts-Datema, W., 2005. Sleep and Student Performance at School. Journal of School Health 75, 248-254

Van Dongen, H.P.A., Maislin, G., Mullington, J.M., Dinges, D.F., 2003. The Cumulative Cost of Additional Wakefulness: Dose-Response Effects on Neurobehavioral Functions and Sleep Physiology From Chronic Sleep Restriction and Total Sleep Deprivation. Sleep 26, 117-126

Varni, J.W., Seid, M., Kurtin, P.S., 2001. PedsQL™ 4.0: Reliability and Validity of the Pediatric Quality of Life Inventory™ Version 4.0 Generic Core Scales in Healthy and Patient Populations. Medical Care 39, 800-812

Vidmar, S.I., Cole, T.J., Pan, H., 2013. Standardizing anthropometric measures in children and adolescents with functions for egen: Update. Stata Journal 13, 366-378

Watson, N.F., Badr, M.S., Belenky, G., Bliwise, D.L., Buxton, O.M., Buysse, D., . . . Tasali, E., 2015. Joint Consensus Statement of the American Academy of Sleep Medicine and Sleep Research Society on the Recommended Amount of Sleep for a Healthy Adult: Methodology and Discussion. Journal of Clinical Sleep Medicine 11, 931-952

Wooldridge, J.M., 2010. Econometric Analysis of Cross Section and Panel Data. MIT Press, Cambridge, Mass.

Table 1: Impact of daylight duration, sunrise time and sunset time on children's time allocation

	Sleep duration (hour/day)	Sleep onset time (24-hour clock)	Wakeup time (24-hour clock)	Personal care (hour/day)	School (hour/day)	Educational (hour/day)	Physical (hour/day)	Chores (hour/day)	Media (hour/day)	Travel (hour/day)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Daylight duration (hour/day)	-0.07***	0.09***	-0.04***	-0.05***	0.09***	0.01	0.10***	-0.00	-0.09***	0.01
	[0.01]	[0.03]	[0.01]	[0.02]	[0.02]	[0.01]	[0.02]	[0.01]	[0.02]	[0.01]
Observations	53,741	53,714	53,740	53,741	53,741	53,741	53,741	53,741	53,741	53,741
No of unique children	8,708	8,708	8,708	8,708	8,708	8,708	8,708	8,708	8,708	8,708
Sample mean (hours)	10.55	20.20	6.94	4.15	1.86	1.00	2.56	0.34	2.19	1.34
R-squared	0.228	0.036	0.132	0.035	0.387	0.052	0.205	0.152	0.245	0.059
F-test	25.83	8.29	8.75	8.27	27.12	0.85	32.25	0.05	25.88	1.79
Sunrise time (24-hour clock)	0.11***	-0.14**	0.09***	0.09***	-0.10***	0.00	-0.13***	-0.02	0.08***	-0.04*
	[0.03]	[0.06]	[0.02]	[0.03]	[0.03]	[0.02]	[0.03]	[0.01]	[0.03]	[0.02]
R-squared	0.228	0.036	0.132	0.035	0.387	0.052	0.205	0.152	0.244	0.059
F-test	20.86	6.25	14.87	6.97	11.25	0.00	18.87	1.78	7.74	3.69
Sunset time (24-hour clock)	-0.09***	0.14**	-0.03	-0.07**	0.16***	0.03	0.15***	-0.02	-0.16***	0.01
	[0.02]	[0.05]	[0.02]	[0.03]	[0.03]	[0.02]	[0.03]	[0.01]	[0.03]	[0.02]
R-squared	0.228	0.036	0.131	0.035	0.387	0.052	0.205	0.152	0.245	0.059
F-test	16.00	6.24	1.67	5.38	29.93	2.11	28.85	2.45	34.42	0.16

Notes: Estimates for each column and panel are from a separate regression model (1). F test refers to the statistic from a t test for statistical significance of the respective independent variable (i.e., daylight duration, sunrise time or sunset time). Other variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Summary statistics such as sample size and sample mean are not reported for the last two panels since they are identical to those reported in the

first panel. Robust standard errors clustered at the individual level are in parentheses. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level

Table 2: Summary statistics by sleep duration

Variable	Longer sleep duration group	Shorter sleep duration group	Longer sleep group - Shorter sleep group
	(1)	(2)	(3)
Child age (years)	6.045	9.659	-3.614***
Male	0.501	0.515	-0.014***
Indigenous	0.021	0.021	0.000
Low birth weight	0.062	0.061	0.001
Mother has a certificate or diploma	0.383	0.404	-0.02***
Mother has a graduate degree	0.364	0.386	-0.022***
Mother ESB migrant	0.097	0.098	0.000
Mother NESB migrant	0.118	0.201	-0.082***
Number of siblings	1.453	1.520	-0.067***
Lived with both parents	0.860	0.816	0.044***
Social development	0.084	-0.010	0.094***
Emotional development	0.046	0.008	0.038***
Physical development	0.066	0.028	0.038***
PedsQL Overall	0.071	0.004	0.067***
Pro-sociality	-0.017	0.047	-0.065***
Hyperactivity	0.034	0.075	-0.041***
Emotional	0.112	0.016	0.096***
Conduct	-0.067	0.134	-0.201***
Peer	0.057	0.037	0.02**
SDQ Overall	0.037	0.091	-0.053***
BMI	0.418	0.512	-0.094***
Underweight	0.057	0.056	0.000
Overweight	0.207	0.239	-0.032***
Waist-for-height ratio	0.486	0.465	0.021***
Excellent health	0.556	0.518	0.038***
Any ongoing condition	0.352	0.442	-0.089***
Prescribed medicine	0.133	0.146	-0.013***
MBS ($1000)	0.204	0.253	-0.049***
PBS ($1000)	0.018	0.042	-0.024**
MBS and PBS ($1000)	0.222	0.295	-0.073***
Matrix reasoning	0.020	0.064	-0.045***
Reading	-0.064	0.365	-0.429***
Writing	-0.014	0.369	-0.384***
Spelling	-0.063	0.382	-0.445***
Grammar	-0.036	0.343	-0.379***
Numeracy	-0.058	0.433	-0.491***
Daylight duration (hour/day)	10.826	11.088	-0.262***
Number of observations	23,109	22,029	

Notes: Figures are sample means. Statistics are calculated using an estimated sample from the FE-IV regression for "Social development" as an outcome. Tests are performed on the significance of the difference between the sample mean for "Shorter sleep duration" individuals (identified as those with sleep duration < median of sleep duration among individuals included in the final sample) and "Longer sleep duration" individuals (sleep duration >=median). The symbol *denotes significance at the 10% level, ** at the 5% level, and *** at the 1% level.

Table 3: Impact of sleep duration on general development and behavioural outcomes - results from FE and FE-IV models

	FE	FE-IV	FE	FE-IV	FE	FE-IV	FE	FE-IV	FE	FE-IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Social development		Emotional development		Physical development		PedsQL Overall		Pro-sociality	
Sleep duration (hour/day)	0.24	6.87	1.25***	17.98*	-0.22	22.59*	0.47**	25.51**	-0.16	-2.23
	[0.23]	[12.13]	[0.23]	[10.67]	[0.23]	[13.25]	[0.22]	[12.03]	[0.24]	[10.14]
Observations	45,138	45,138	46,142	46,142	45,133	45,133	43,540	43,540	40,422	40,422
Individuals	8,222	8,222	8,264	8,264	8,210	8,210	8,114	8,114	7,962	7,962
Mean of dep. variable	0.04	0.04	0.01	0.01	0.04	0.04	0.04	0.04	0.00	0.00
F-statistic of IV		21.55		27.68		22.38		23.47		27.34
Hausman test (p value)		0.58		0.10		0.06		0.02		0.84
	Hyperactivity		Emotional symptoms		Conduct		Peer problem		SDQ Overall	
Sleep duration (hour/day)	0.26	-2.85	0.78***	14.25	0.64***	10.12	0.20	-11.79	0.51**	2.07
	[0.21]	[8.95]	[0.25]	[10.67]	[0.23]	[9.65]	[0.25]	[10.90]	[0.20]	[8.60]
Observations	40,415	40,415	40,419	40,419	40,420	40,420	40,422	40,422	40,408	40,408
Individuals	7,960	7,960	7,961	7,961	7,962	7,962	7,962	7,962	7,959	7,959
Mean of dep. variable	0.04	0.04	0.05	0.05	0.02	0.02	0.03	0.03	0.04	0.04
F-statistic of IV		27.49		27.22		27.29		27.38		27.39
Hausman test (p value)		0.73		0.19		0.32		0.26		0.86

Notes: FE results are from the regression (1) while FE-IV results from models (1) and (2). F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration. Other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Table 4: Impact of sleep duration on anthropometric and health outcomes - results from FE and FE-IV models

	FE	FE-IV	FE	FE-IV	FE	FE-IV	FE	FE-IV	FE	FE-IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	BMI		Underweight		Overweight		Waist-for-height ratio		Excellent health	
Sleep duration (hour/day)	-0.40**	20.94**	0.05	-1.30	-0.15*	8.17*	-0.01	0.82	0.29**	-0.69
	[0.20]	[10.50]	[0.05]	[2.84]	[0.09]	[4.73]	[0.01]	[0.53]	[0.12]	[5.87]
Observations	46,600	46,600	46,638	46,638	46,638	46,638	46,496	46,496	53,692	53,692
Individuals	8,321	8,321	8,324	8,324	8,324	8,324	8,311	8,311	8,699	8,699
Mean of dep. variable	0.46	0.46	0.06	0.06	0.22	0.22	0.48	0.48	0.55	0.55
F-statistic of IV		24.46		24.62		24.62		24.84		25.48
Hausman test (p value)		0.03		0.63		0.06		0.10		0.87
	Any ongoing condition		Prescribed medicine		MBS ($1000)		PBS ($1000)		MBS and PBS ($1000)	
Sleep duration (hour/day)	-0.26**	3.10	0.06	-2.47	-0.23	9.83*	-0.31	-7.08	-0.54	2.75
	[0.13]	[5.47]	[0.08]	[4.02]	[0.17]	[5.21]	[0.36]	[8.62]	[0.39]	[9.79]
Observations	41,363	41,363	53,687	53,687	53,001	53,001	53,002	53,002	53,001	53,001
Individuals	8,109	8,109	8,699	8,699	8,546	8,546	8,546	8,546	8,546	8,546
Mean of dep. variable	0.40	0.40	0.14	0.14	0.24	0.24	0.03	0.03	0.27	0.27
F-statistic of IV		29.43		25.64		26.91		26.85		26.91
Hausman test (p value)		0.54		0.53		0.04		0.41		0.73

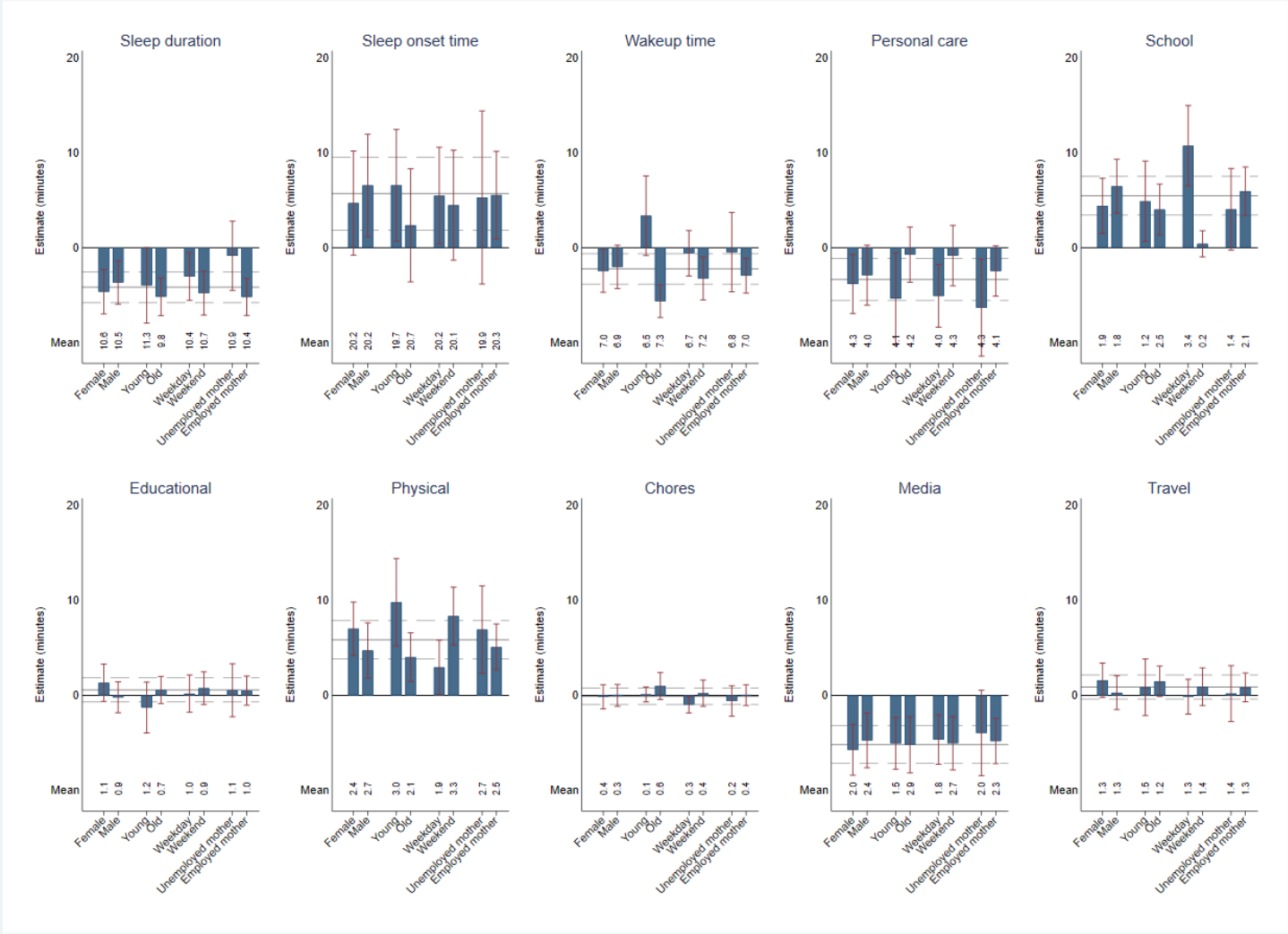
Notes: FE results are from the regression (1) while FE-IV results from models (1) and (2). F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration. Other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Table 5: Impact of sleep duration on cognitive outcomes - results from FE and FE-IV models

	FE	FE-IV	FE	FE-IV	FE	FE-IV
	(1)	(2)	(3)	(4)	(5)	(6)
	Matrix reasoning		Reading		Writing	
Sleep duration (hour/day)	-0.19	15.72	0.22	5.41	-0.39	-0.43
	[0.36]	[10.42]	[0.21]	[6.11]	[0.29]	[9.15]
Observations	14,384	14,384	18,854	18,854	18,849	18,849
Individuals	3,519	3,519	5,503	5,503	5,506	5,506
Mean of dep. variable	0.08	0.08	0.17	0.17	0.20	0.20
F-statistic of IV		30.20		26.75		26.35
Hausman test (p value)		0.11		0.39		1.00
	Spelling		Grammar		Numeracy	
Sleep duration (hour/day)	0.18	10.58**	0.40*	3.41	0.14	-1.23
	[0.16]	[5.17]	[0.24]	[7.14]	[0.19]	[5.42]
Observations	18,881	18,881	18,876	18,876	18,742	18,742
Individuals	5,510	5,510	5,509	5,509	5,472	5,472
Mean of dep. variable	0.18	0.18	0.17	0.17	0.21	0.21
F-statistic of IV		25.79		25.78		25.52
Hausman test (p value)		0.03		0.67		0.80

Notes: FE results are from the regression (1) while FE-IV results from models (1) and (2). F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration. Other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Figure 1: Heterogenous impacts of daylight duration on study children's time allocation



Notes: Results (coefficient estimates and 95% confidence intervals which are multiplied by 60 for aesthetic purposes so the coefficient estimates can be interpreted in minutes) for different sub-populations are obtained from separate FE regressions using Equation (1). The solid (dash) horizontal line shows the daylight duration coefficient (95% confidence interval) estimates for the whole population. The sample mean of the dependent variable, represented in hours, for each sub-population is printed below the bars.

Online Appendix

for refereeing purposes and to be published online

Appendix A reports additional results.

Appendix B describes coding rules for activities.

Appendix C reports results from robustness checks for the estimated relationship between daylight duration and children's time allocation.

Appendix Table A1: Variable description and summary statistics

Variable	Description	Mean	Min	Max	Standard deviations		
					Overall	Between	Within
Child age	SC age at the survey time (years)	6.84	0.00	16.00	4.51	2.67	3.94
Male	Dummy = 1 if SC is a male, = 0 if female	0.51	0.00	1.00	0.50	0.50	0.00
Indigenous	Dummy: = 1 if SC has Aboriginal/Torres Strait Islander origin, = 0 otherwise	0.02	0.00	1.00	0.15	0.17	0.00
Low birth weight	Dummy: = 1 if SC's birth weight is 2500 grams or less, = 0 otherwise	0.06	0.00	1.00	0.24	0.25	0.00
Mother has a certificate	Dummy: = 1 if SC's mother has advanced diploma/diploma, = 0 otherwise	0.39	0.00	1.00	0.49	0.46	0.17
Mother has a graduate degree	Dummy: = 1 if SC's mother has a bachelor degree or higher, = 0 otherwise	0.37	0.00	1.00	0.48	0.46	0.13
Mother ESB migrant	Dummy: = 1 if SC's mother was born overseas in an English-Speaking Background (ESB) country, = 0 otherwise	0.10	0.00	1.00	0.30	0.29	0.02
Mother NESB migrant	Dummy: = 1 if SC's mother was born overseas in a Non-ESB (NESB) country, = 0 otherwise	0.16	0.00	1.00	0.36	0.33	0.19
Number of siblings	Number of siblings	1.41	0.00	11.00	1.00	0.96	0.44
Lived with both parents	Dummy: = 1 if SC lived with both parents at the survey time, = 0 otherwise	0.85	0.00	1.00	0.36	0.34	0.18
Sleep onset time	Time the SC went to sleep on the diary date (hour, 24-hour clock)	20.20	0.00	23.98	3.48	1.73	3.14
Wakeup time	Time the SC woke up on the diary date (hour, 24-hour clock)	6.94	0.00	17.25	1.89	1.15	1.60
Sleep duration	Total time spent on sleeping and napping per TUD day (hour/day)	10.55	0.00	22.75	2.03	1.16	1.75
Personal care	Total time spent on personal care per TUD day (hour/day)	4.15	0.00	20.00	2.28	1.24	1.99
School	Total time spent on school related activities per TUD day (hour/day)	1.86	0.00	19.75	2.81	1.23	2.58
Educational activity	Total time spent on sleeping and napping per TUD day (hour/day)	1.00	0.00	14.42	1.33	0.74	1.14
Physical activity	Total time spent on sleeping and napping per TUD day (hour/day)	2.56	0.00	23.75	2.29	1.12	2.06
Chores	Total time spent on sleeping and napping per TUD day (hour/day)	0.34	0.00	11.50	0.77	0.38	0.69
Media activity	Total time spent on sleeping and napping per TUD day (hour/day)	2.19	0.00	18.75	2.12	1.24	1.81
Travel	Total time spent on sleeping and napping per TUD day (hour/day)	1.34	0.00	18.50	1.40	0.71	1.25
Sunrise time	Sunrise time on the TUD date (hour, 24-hour clock)	6.73	4.69	7.81	0.54	0.40	0.39
Sunset time	Sunset time on the TUD date (hour, 24-hour clock)	17.66	16.68	20.95	0.73	0.48	0.60
Daylight duration	Daylight duration on the TUD date (hour/day)	10.93	8.98	15.01	1.07	0.66	0.90

Notes: Statistics are calculated using an estimated sample from the regression of sleep duration on daylight duration from Equation (1). English-Speaking Background (ESB) countries include UK, Ireland, Canada, New Zealand, South Africa and USA. SC refers to the Study Child. "P1" indicates Parent 1's reported measures while "ITV" refers to the Interviewer's. "ADM" indicates linked administrative data sources.

Appendix Table A1: Variable description and summary statistics (continued)

Variable	Description	Mean	Min	Max	Standard deviations		
					Overall	Between	Within
Social development	PedsQL social development sub-scale - Standardized - P1	0.04	-4.94	1.06	0.97	0.79	0.63
Emotional development	PedsQL emotional development sub-scale - Standardized - P1	0.01	-4.68	1.64	0.98	0.80	0.61
Physical development	PedsQL physical development sub-scale - Standardized - P1	0.03	-5.46	1.13	0.94	0.75	0.65
PedsQL Overall	Mean of above three PedsQL sub-scales - Standardized - P1	0.04	-5.85	1.53	0.95	0.82	0.59
Pro-sociality	SDQ Pro-social behaviour scale - Standardized - P1	0.00	-4.63	1.04	0.99	0.83	0.60
Hyperactivity	SDQ Hyperactivity and inattention scale (reversed) - Standardized - P1	0.04	-2.95	1.36	0.98	0.87	0.52
Emotional	SDQ Emotional symptoms scale (reversed) - Standardized - P1	0.05	-4.51	0.95	0.96	0.81	0.60
Conduct	SDQ Conduct problems scale (reversed) - Standardized - P1	0.02	-5.20	0.90	0.99	0.84	0.62
Peer	SDQ Peer-relationship problems scale (reversed) - Standardized - P1	0.03	-5.29	0.92	0.98	0.83	0.60
SDQ Overall	Mean of above five SDQ sub-scales - Standardized - P1	0.04	-5.18	1.55	0.98	0.88	0.50
BMI	SC's Body Mass Index (gender- and age-standardized z-scores) - ITV	0.46	-4.97	4.85	1.11	1.00	0.54
Underweight	SC's gender- and age-standardized BMI is categorized as underweight, = 0 otherwise - ITV	0.06	0.00	1.00	0.23	0.18	0.16
Overweight	SC's gender- and age-standardized BMI is categorized as overweight or obese, = 0 otherwise - ITV	0.22	0.00	1.00	0.42	0.35	0.25
Waist-for-height ratio	SC's waist circumference at the time of survey (cm) - ITV	0.48	0.15	1.01	0.06	0.04	0.04
Excellent health	Dummy: = 1 if SC's health is in excellent condition, - 0 otherwise - P1	0.55	0.00	1.00	0.50	0.36	0.37
Any ongoing condition	Dummy: = 1 if SC has any ongoing medical condition, - 0 otherwise - P1	0.40	0.00	1.00	0.49	0.36	0.35
Prescribed medicine	Dummy: = 1 if SC currently uses prescribed medicine, - 0 otherwise - P1	0.14	0.00	1.00	0.34	0.25	0.25
MBS	Medicare Benefit Scheme amount during the survey year (AU$1000) - ADM	0.24	0.00	30.68	0.41	0.27	0.32
PBS	Pharmaceutical Benefit Scheme amount during the survey year (AU$1000) - ADM	0.03	0.00	209.51	0.96	0.44	0.85
MBS and PBS	Medicare and Pharmaceutical Benefit Scheme amount during the survey year (AU$1000) - ADM	0.27	0.00	212.74	1.07	0.55	0.92
Matrix reasoning	Matrix reasoning test score - Standardized - ITV	0.04	-3.17	2.79	0.99	0.92	0.49
Reading	NAPLAN Reading test score - Standardized - ADM	0.18	-5.20	3.94	0.96	0.79	0.57
Writing	NAPLAN Writing test score - Standardized - ADM	0.20	-4.58	3.52	0.99	0.83	0.62
Spelling	NAPLAN Spelling test score - Standardized - ADM	0.19	-3.33	3.44	0.97	0.81	0.57
Grammar	NAPLAN Grammar test score - Standardized - ADM	0.18	-3.77	3.70	0.96	0.79	0.57
Numeracy	NAPLAN Numeracy test score - Standardized - ADM	0.23	-5.10	4.11	0.97	0.80	0.58

Notes: Statistics are calculated using an estimated sample from the regression of sleep duration on daylight duration from Equation (1). English-Speaking Background (ESB) countries include UK, Ireland, Canada, New Zealand, South Africa and USA. SC refers to the Study Child. “P1” indicates Parent 1’s reported measures while “ITV” refers to the Interviewer’s. “ADM” indicates linked administrative data sources.

Appendix Table A2: LSAC contents by wave and cohort

LSAC wave	1	2	3	4	5	6	7	8	9
LSAC survey year	2004	2006	2008	2010	2012	2014	2016	2018	2020/21
Age									
B cohort	0/1	2/3	4/5	6/7	8/9	10/11	12/13	14/15	16/17
K cohort	4/5	6/7	8/9	10/11	12/13	14/15	16/17	18/19	20/21
TUD - P1 (wave 1 to 3) or SC (from wave 4)	BK	BK	BK	K	K	BK	B	B	
PedsQL measures - P1	K	BK	BK	BK	BK	BK	BK	B	
SDQ - P1	K	K	BK	BK	BK	BK	BK	B	
Weight - ITV	BK	BK	BK	BK	BK	BK	BK	BK	
Height - ITV	K	BK	BK	BK	BK	BK	BK	BK	
Waist circumference - ITV	K	BK	BK	BK	BK	BK	BK	BK	
Excellent health - P1	BK	BK	BK	BK	BK	BK	BK	BK	
Any ongoing condition - P1		BK	BK	BK	BK	BK	BK	BK	
Prescribed medicine - P1	BK	BK	BK	BK	BK	BK	BK	B	
MBS and PBS	BK	BK	BK	BK	BK	BK	BK	BK	
MR - ITV		K	K	BK	B	B			
NAPLAN test grade assigned									
B cohort				3	5	7	9		
K cohort		3	5	7	9				

Notes: "Y" indicates information is available in respective survey wave. SDQ = Strengths and Difficulties Questionnaire; MR = Matrix Reasoning; NAPLAN = National Assessment Program – Literacy and Numeracy test score; P1 - reported by Parent 1; P2 - reported by Parent 2; TC - reported by Teacher; SC – reported by Study Child; ITV – assessed by Interviewer.

Appendix Table A3: Raw correlations among sleep related variables in LSAC

Variable	Correlations												Summary statistics		
	Sleep duration (hour)	Sleep onset time (24-hour clock)	Wakeup time (24-hour clock)	SC sleep enough	SC's sleep quality	SC goes to bed at regular times	Bed time - School night (24-hour clock)	Bed time - No school next day (24-hour clock)	Sleep onset time - School night (24-hour clock)	Sleep onset time - No school next day (24-hour clock)	Wakeup time - School night (24-hour clock)	Wakeup time - No school next day (24-hour clock)	Mean	Min	Max
Sleep duration (hour) [a]	1.00												10.48	0.00	22.75
Sleep onset time (24-hour clock) [a]	0.29	1.00											20.08	0.00	23.98
Wakeup time (24-hour clock) [a]	0.25	0.23	1.00										6.94	0.00	17.25
SC sleep enough [b]	-0.08	-0.07	0.05	1.00									1.81	1.00	4.00
SC's sleep quality [c]	-0.07	-0.06	0.03	0.54	1.00								1.76	1.00	4.00
SC goes to bed at regular times [d]	-0.06	0.04	0.07	0.13	0.10	1.00							1.67	1.00	5.00
Bed time - School night (24-hour clock) [e]	-0.08	0.08	0.11			0.19	1.00						20.98	0.00	23.98
Bed time - No school next day (24-hour clock) [e]	0.09	0.22	-0.06	-0.15	-0.11	-0.09	0.15	1.00					19.69	0.00	23.98
Sleep onset time - School night (24-hour clock) [e]		0.23		-0.12	-0.11		0.49	0.26	1.00				20.98	0.00	23.98
Sleep onset time - No school next day (24-hour clock) [e]	0.12	0.27	-0.12	-0.21	-0.16	-0.14	0.06	0.70	0.27	1.00			18.51	0.00	23.98
Wakeup time - School night (24-hour clock) [e]	0.15	-0.03	0.33	0.03	0.03	0.14		-0.10	-0.09	-0.13	1.00		6.86	0.00	14.00
Wakeup time - No school next day (24-hour clock) [e]	0.05	-0.12	0.39	0.17	0.13	0.21	0.03	-0.27	-0.09	-0.33	0.34	1.00	8.57	0.00	15.00

Notes: Only correlation is statistically significant at 1% level is listed. [a] indicates variables which are derived from TUDs and described in the text.
[b] "SC sleep enough" is derived from responses to a question, asking the study child about "During the last month, do you think you usually got enough sleep?". Responses are coded as: 1 Plenty; 2 Just enough; 3 Not quite enough; 4 Not nearly enough. This question is asked in waves 4 to 8 for K cohort and waves 6 to 8 for B cohort.
[c] "SC's sleep quality" is derived from responses to a question, asking the study child about "During the last month, how well do you feel you have slept in general?". Responses are coded as: 1 Very well; 2 Fairly well; 3 Fairly badly; 4 Very badly. This question is asked in waves 4 to 8 for K cohort and waves 6 to 8 for B cohort.
[d] "SC goes to bed at regular times" is derived from responses to a question asking the corresponding parent about "Does the study child go to bed at regular times?". Responses are coded as: 1 Always; 2 Usually; 3 Sometimes; 4 Rarely; 5 Never. This question is asked in waves 2 to 5 for K cohort and waves 2 to 7 for B cohort.

[e] These time variables are derived from responses to a respective question asking the study child “About what time do you go to bed on a usual school night?”, “About what time do you fall asleep on the nights you do not have school the next day?”, “About what time do you go to sleep on a usual school night?”, “About what time do you fall asleep on the nights you do not have school the next day?”, “About what time do you wake up in the morning on a usual school day?”, and “About what time do you wake up on the days you do not have school?”. This question is asked in waves 5 to 7 for K cohort and waves 6 to 8 for B cohort.

Appendix Table A4: Time allocation responses to daylight duration – Remaining results

	Sleep duration (hour/day)	Sleep onset time (24-hour clock)	Wakeup time (24-hour clock)	Personal care (hour/day)	School (hour/day)	Educational (hour/day)	Physical (hour/day)	Chores (hour/day)	Media (hour/day)	Travel (hour/day)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Child age (months)	-8.30***	26.08***	15.18***	-12.14***	19.58***	9.73***	-4.47*	-4.58***	4.24*	-4.06**
	[2.08]	[4.53]	[2.06]	[2.74]	[2.49]	[1.66]	[2.47]	[0.97]	[2.40]	[1.65]
Child age squared	0.65***	-1.27***	-0.99***	0.81***	-0.83***	-0.60***	-0.19***	0.20***	-0.29***	0.26***
	[0.04]	[0.10]	[0.04]	[0.05]	[0.04]	[0.03]	[0.05]	[0.02]	[0.05]	[0.03]
Mother education: Certificate [a]	2.24	-1.26	-2.48	-8.72**	1.19	-3.72	-0.38	-2.12	6.65	4.86**
	[3.35]	[7.87]	[3.33]	[4.42]	[3.86]	[2.71]	[3.94]	[1.62]	[4.07]	[2.35]
Mother education: Graduate [a]	0.96	10.23	0.99	-8.56	10.37**	0.11	-4.49	0.90	-1.89	2.58
	[4.48]	[10.59]	[4.54]	[5.82]	[5.14]	[3.56]	[5.04]	[2.29]	[5.35]	[3.24]
Number of siblings	-3.03**	-5.92**	-4.14***	6.60***	-1.72	2.09**	-0.39	1.46**	-4.25***	-0.76
	[1.21]	[2.43]	[1.28]	[1.53]	[1.28]	[0.89]	[1.35]	[0.59]	[1.38]	[0.90]
Living with both parents	-0.33	14.73**	-4.93*	7.72**	-0.48	10.57***	-0.41	3.24**	-13.38***	-6.94***
	[2.91]	[6.38]	[2.97]	[3.80]	[3.16]	[2.18]	[3.26]	[1.27]	[3.40]	[2.07]
Second quarter [b]	3.82	-9.81	0.85	-6.55	22.65***	0.70	-9.81**	-1.56	-6.45*	-2.79
	[4.07]	[6.59]	[4.14]	[4.91]	[4.35]	[3.32]	[4.47]	[1.31]	[3.59]	[2.93]
Third quarter [b]	4.98	-17.60**	12.04***	-4.60	10.71**	0.57	-13.01***	0.60	3.94	-3.18
	[4.13]	[6.84]	[4.25]	[5.08]	[4.53]	[3.41]	[4.59]	[1.40]	[3.72]	[3.02]
Fourth quarter [b]	3.96	-27.02***	12.66***	-1.51	3.87	-1.63	-15.68***	4.11**	10.63**	-3.74
	[4.52]	[8.51]	[4.59]	[5.74]	[5.11]	[3.65]	[5.21]	[1.86]	[4.50]	[3.32]
Monday [c]	-17.50***	-2.36	-16.29***	-18.50***	151.76***	2.27*	-73.50***	-6.06***	-28.62***	-9.85***
	[1.64]	[3.08]	[1.59]	[2.09]	[2.21]	[1.16]	[1.94]	[0.68]	[1.71]	[1.30]
Tuesday [c]	-22.01***	-2.10	-21.23***	-25.15***	173.61***	4.94***	-80.62***	-7.19***	-34.64***	-8.93***
	[1.60]	[3.17]	[1.59]	[2.11]	[2.31]	[1.15]	[1.90]	[0.69]	[1.75]	[1.25]
Wednesday [c]	-21.98***	-5.16	-20.61***	-25.88***	174.64***	6.34***	-84.17***	-6.86***	-33.60***	-8.49***
	[1.56]	[3.15]	[1.55]	[2.10]	[2.29]	[1.21]	[1.87]	[0.71]	[1.69]	[1.28]
Thursday [c]	-24.98***	-1.21	-21.18***	-24.01***	173.74***	4.56***	-82.14***	-6.88***	-35.90***	-4.38***
	[1.67]	[3.12]	[1.57]	[2.14]	[2.44]	[1.19]	[1.93]	[0.67]	[1.71]	[1.32]
Friday [c]	-44.78***	-3.94	-24.37***	-21.42***	168.64***	-3.47***	-70.40***	-8.27***	-22.98***	2.68*
	[1.75]	[3.62]	[1.66]	[2.21]	[2.42]	[1.23]	[1.99]	[0.69]	[1.73]	[1.41]
Saturday [c]	-28.39***	-0.99	-8.78***	1.39	-3.17**	-0.48	12.46***	-0.90	4.40***	14.69***
	[1.65]	[3.10]	[1.66]	[2.03]	[1.55]	[1.11]	[2.09]	[0.62]	[1.57]	[1.37]
Holidays	1.02	-12.64***	28.42***	0.90	-136.83***	-10.96***	64.73***	11.64***	53.59***	15.91***
	[1.45]	[3.36]	[1.33]	[1.83]	[1.61]	[1.01]	[1.93]	[0.79]	[1.76]	[1.26]

Notes: Results are from the FE regression. Coefficient estimates and standard errors are multiplied by 60 for aesthetic purposes. [a], [b], and [c] denotes having year 12 or below qualification, first quarter and Sunday as the base group, respectively. Other variables include local socio-economic background variables, state/territory dummies, and TUD year dummies. Robust standard errors clustered at the individual level are in parentheses. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A5: Time allocation responses to daylight duration - Robustness checks

	Sleep duration (hour/day)	Sleep onset time (24-hour clock)	Wakeup time (24-hour clock)	Personal care (hour/day)	School (hour/day)	Educational (hour/day)	Physical (hour/day)	Chores (hour/day)	Media (hour/day)	Travel (hour/day)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A: Using a pooled OLS regression model										
Daylight duration (hour/day)	-0.08***	0.09***	-0.02	-0.06***	0.10***	0.01	0.10***	0.00	-0.09***	0.01
	[0.01]	[0.03]	[0.01]	[0.02]	[0.02]	[0.01]	[0.02]	[0.01]	[0.02]	[0.01]
Observations	54,037	54,010	54,036	54,037	54,037	54,037	54,037	54,037	54,037	54,037
R-squared	0.263	0.069	0.181	0.083	0.398	0.103	0.213	0.197	0.283	0.084
F-test	32.24	9.75	2.47	10.60	38.28	0.36	43.04	0.01	31.62	1.62
Panel B: Excluding child or household level variables in a FE regression model										
Daylight duration (hour/day)	-0.07***	0.10***	-0.04***	-0.06***	0.09***	0.01	0.10***	-0.00	-0.08***	0.01
	[0.01]	[0.03]	[0.01]	[0.02]	[0.02]	[0.01]	[0.02]	[0.01]	[0.02]	[0.01]
Observations	53,905	53,878	53,904	53,905	53,905	53,905	53,905	53,905	53,905	53,905
No of unique children	8,738	8,738	8,738	8,738	8,738	8,738	8,738	8,738	8,738	8,738
R-squared	0.223	0.030	0.118	0.028	0.383	0.040	0.204	0.149	0.243	0.057
F-test	28.59	9.27	7.17	9.53	28.64	1.51	34.68	0.10	25.00	1.31

Notes: Estimates for each column and panel are from a separate regression. An Ordinary Least Squares (OLS) regression model is used in Panel A while a FE regression model for Panel B. Other variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. For OLS regressions, we also control for child gender, Aboriginal status, low birthweight status, cohort dummy, maternal migration statuses and postcode dummies. Robust standard errors clustered at the individual level are in parentheses. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A5: Time allocation responses to daylight duration - Robustness checks (continued)

	Sleep duration (hour/day)	Sleep onset time (24-hour clock)	Wakeup time (24-hour clock)	Personal care (hour/day)	School (hour/day)	Educational (hour/day)	Physical (hour/day)	Chores (hour/day)	Media (hour/day)	Travel (hour/day)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel C: Including local weather conditions on TUD date in a FE regression model										
Daylight duration (hour/day)	-0.07***	0.04	-0.04**	-0.04*	0.10***	0.02*	0.03	0.00	-0.07***	0.02
	[0.02]	[0.04]	[0.02]	[0.02]	[0.02]	[0.01]	[0.02]	[0.01]	[0.02]	[0.01]
Daily maximum temperature (°F)	0.02*	0.02	0.00	-0.03**	0.03**	-0.02**	0.04***	-0.01	-0.05***	0.01
	[0.01]	[0.02]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.00]	[0.01]	[0.01]
Daily maximum temperature squared	-0.00**	-0.00	-0.00	0.00**	-0.00***	0.00**	-0.00***	0.00	0.00***	-0.00*
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Daily precipitation (inches)	0.00	0.00	0.00	0.00	-0.00	0.01***	-0.01***	-0.00	0.01***	-0.00*
	[0.00]	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Observations	53,741	53,714	53,740	53,741	53,741	53,741	53,741	53,741	53,741	53,741
No of unique children	8,708	8,708	8,708	8,708	8,708	8,708	8,708	8,708	8,708	8,708
R-squared	0.228	0.036	0.132	0.035	0.387	0.052	0.206	0.152	0.245	0.059
F-test	20.17	1.34	5.00	3.82	24.78	3.27	2.39	0.35	12.20	2.51

Notes: Estimates for each column and panel are from a separate regression. An Ordinary Least Squares (OLS) regression model is used in Panel A while a FE regression model for Panel B. Other variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. For OLS regressions, we also control for child gender, Aboriginal status, low birthweight status, cohort dummy, maternal migration statuses and postcode dummies. Robust standard errors clustered at the individual level are in parentheses. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A6: First stage regression results

Specification	POLS	FE
	(1)	(2)
Daylight duration (hour/day)	-4.11***	-3.88***
	[0.77]	[0.84]
Child age	-10.62***	-2.20
	[1.45]	[2.10]
Child age squared	0.21***	0.20***
	[0.04]	[0.05]
Male	-1.78	
	[1.11]	
Aboriginal	1.01	
	[4.02]	
Low birthweight	6.12***	
	[2.27]	
Mother with certificate/diploma [a]	-2.86**	5.10
	[1.45]	[3.50]
Mother with bachelor or higher degree [a]	-3.95***	2.64
	[1.52]	[4.52]
Mother ESB migrant [b]	-2.75	
	[1.83]	
Mother NESB migrant [b]	-6.54***	
	[1.99]	
Number of siblings	-0.01	-4.71***
	[0.56]	[1.25]
Living with both parents	-1.41	1.21
	[1.49]	[2.86]
Second quarter [c]	8.76**	-158.55***
	[3.85]	[32.45]
Third quarter [c]	13.31***	9.26**
	[3.82]	[4.12]
Fourth quarter [c]	15.58***	10.68**
	[4.07]	[4.19]
Monday [d]	-22.02***	-20.40***
	[1.59]	[1.71]
Tuesday [d]	-26.31***	-26.08***
	[1.54]	[1.65]
Wednesday [d]	-25.56***	-25.15***
	[1.52]	[1.61]
Thursday [d]	-27.60***	-28.04***
	[1.63]	[1.71]
Friday [d]	-52.82***	-51.99***
	[1.72]	[1.83]
Saturday [d]	-32.56***	-32.82***
	[1.71]	[1.76]
Holidays	7.23***	6.27***
	[1.38]	[1.46]
Observations	45,524	45,138
Number of unique individuals		8,222

Notes: POLS results are from the first stage of pooled IV regression of "Social development" as an outcome while FE results from the FE-IV regression. Coefficient estimates and standard errors are multiplied by 60 for aesthetic purposes. [a], [b], [c] and [d] denotes having year 12 or below qualification, Australian born mother, first quarter and

Sunday as the base group, respectively. Other variables include local socio-economic background variables, state/territory dummies, and TUD year dummies. For OLS regression, we also control for child gender, Aboriginal status, low birthweight status, cohort dummy, and maternal migration statuses. Robust standard errors clustered at the individual level are in parentheses. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A7: Second stage regression results

	Social development	Emotional development	Physical development	PedsQL Overall	Pro-sociality	Hyperactivity	Emotional symptoms	Conduct	Peer problem	SDQ Overall	BMI	Underweight	Overweight
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Child age	-7.83***	-4.30**	4.33*	-1.25	22.57***	-5.21***	-1.76	15.19***	5.15**	9.31***	-7.25***	0.79	-1.75**
	[2.09]	[2.07]	[2.23]	[2.18]	[2.17]	[1.92]	[2.29]	[2.13]	[2.31]	[1.86]	[2.00]	[0.54]	[0.88]
Child age squared	0.52***	0.21***	-0.23***	0.11*	-1.13***	0.25***	0.10*	-0.76***	-0.03	-0.41***	0.27***	-0.01	0.06**
	[0.06]	[0.06]	[0.07]	[0.06]	[0.06]	[0.05]	[0.06]	[0.05]	[0.06]	[0.05]	[0.06]	[0.02]	[0.03]
Mother education: Certificate [(a)]	-13.08***	-7.16**	-9.63**	-13.27***	-3.25	0.87	-7.17*	-1.99	-8.13**	-5.32*	6.90*	-0.12	2.04
	[3.62]	[3.57]	[3.79]	[3.76]	[3.75]	[3.30]	[3.86]	[3.90]	[3.77]	[3.22]	[3.71]	[0.79]	[1.55]
Mother education: Graduate [(a)]	-16.67***	-13.21***	-3.33	-13.62***	-4.14	3.40	-9.66*	-4.45	-8.01	-5.98	3.77	0.43	0.54
	[4.65]	[4.79]	[4.95]	[5.00]	[4.90]	[4.38]	[5.28]	[4.80]	[5.17]	[4.30]	[4.76]	[1.09]	[2.10]
Number of siblings	-1.08	1.04	4.76***	3.06*	-6.40***	3.37**	4.27***	-3.39**	-1.93	-0.69	-2.67*	-0.07	-0.91
	[1.60]	[1.55]	[1.57]	[1.67]	[1.59]	[1.40]	[1.65]	[1.61]	[1.69]	[1.40]	[1.53]	[0.36]	[0.66]
Living with both parents	13.73***	22.05***	10.93***	18.77***	14.68***	7.42***	16.74***	4.06	9.45***	15.32***	-8.18***	-0.03	-4.63***
	[3.04]	[3.11]	[3.18]	[3.11]	[3.18]	[2.78]	[3.35]	[3.14]	[3.16]	[2.74]	[3.05]	[0.73]	[1.31]
Second quarter [(b)]	-2.90	4.48	-3.28	-2.94	2.78	-1.46	-2.08	3.23	-0.20	0.43	0.67	-1.93	1.13
	[4.87]	[4.42]	[5.31]	[5.02]	[4.40]	[3.82]	[4.68]	[4.86]	[4.70]	[3.82]	[4.47]	[1.30]	[1.91]
Third quarter [(b)]	-4.82	4.87	-5.34	-4.67	4.47	-1.67	-2.32	5.36	-3.09	0.54	1.38	-2.10	0.41
	[5.03]	[4.60]	[5.44]	[5.16]	[4.53]	[3.92]	[4.81]	[4.96]	[4.82]	[3.94]	[4.60]	[1.35]	[1.99]
Fourth quarter [(b)]	-6.76	4.76	0.18	-1.47	3.97	-2.23	-5.24	4.13	-8.02*	-2.21	3.03	-2.30*	1.61
	[4.46]	[4.40]	[4.92]	[4.76]	[4.34]	[3.81]	[4.67]	[4.86]	[4.68]	[3.81]	[4.18]	[1.22]	[1.83]
Monday [(c)]	3.66	6.51	10.23**	10.08**	-0.06	-0.54	6.57	5.07	-2.58	2.37	5.58	0.07	2.57
	[4.30]	[3.98]	[4.93]	[4.37]	[3.82]	[3.40]	[4.03]	[3.63]	[4.12]	[3.24]	[3.80]	[1.03]	[1.71]
Tuesday [(c)]	2.69	6.44	9.50	9.99*	-0.93	-0.51	7.15	5.33	-6.15	1.46	9.72**	-0.78	2.62
	[5.40]	[4.67]	[5.81]	[5.32]	[4.76]	[4.20]	[4.94]	[4.50]	[5.08]	[4.01]	[4.66]	[1.26]	[2.09]
Wednesday [(c)]	3.19	5.50	8.52	9.18*	0.33	-0.33	6.91	4.35	-5.68	1.67	8.11*	-0.32	2.70
	[5.21]	[4.66]	[5.70]	[5.15]	[4.64]	[4.11]	[4.93]	[4.44]	[5.01]	[3.95]	[4.58]	[1.24]	[2.06]
Thursday [(c)]	3.15	6.48	11.02*	11.07*	-0.44	-0.91	7.10	5.13	-4.64	1.76	7.51	-0.23	3.06
	[5.79]	[5.13]	[6.37]	[5.71]	[5.14]	[4.55]	[5.43]	[4.91]	[5.54]	[4.37]	[5.17]	[1.40]	[2.33]
Friday [(c)]	7.54	16.29*	20.52*	22.87**	-0.27	-1.19	13.55	12.65	-11.05	3.88	16.24*	-0.69	6.16
	[10.55]	[9.22]	[11.44]	[10.39]	[9.32]	[8.23]	[9.79]	[8.87]	[10.01]	[7.90]	[9.06]	[2.45]	[4.09]
Saturday [(c)]	4.36	9.61*	12.90*	14.09**	0.19	-1.00	9.44	6.77	-6.82	2.46	10.20*	-0.67	3.74
	[6.71]	[5.80]	[7.24]	[6.69]	[6.26]	[5.54]	[6.61]	[5.95]	[6.74]	[5.32]	[5.72]	[1.54]	[2.58]
Holidays	-1.53	-1.39	-2.74	-3.45*	-1.07	-1.23	-2.66	-1.80	1.06	-1.69	-1.97	-0.03	-1.46**
	[1.67]	[1.57]	[1.90]	[1.85]	[2.08]	[1.82]	[2.21]	[1.94]	[2.24]	[1.75]	[1.46]	[0.38]	[0.66]
Observation	45,138	46,142	45,133	43,540	40,422	40,415	40,419	40,420	40,422	40,408	46,600	46,638	46,638
Number of unique individuals	8,222	8,264	8,210	8,114	7,962	7,960	7,961	7,962	7,962	7,959	8,321	8,324	8,324

Notes: Results are from the FE-IV regression. Coefficient estimates and standard errors are multiplied by 100 for aesthetic purposes. [(a)], [(b)], and [(c)] denotes having year 12 or below qualification, first quarter and Sunday as the base group, respectively. Other variables include local socio-economic background variables, state/territory dummies, and

TUD year dummies. Robust standard errors clustered at the individual level are in parentheses. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A7: Second stage regression results (continued)

	Waist-for-height ratio	Excellent health	Any ongoing condition	Prescribed medicine	MBS ($1000)	PBS ($1000)	MBS and PBS ($1000)	Matrix reasoning	Reading	Writing	Spelling	Grammar	Numeracy
	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
Child age	-1.40***	-0.25	-2.27**	-1.83**	-2.74**	-2.03	-4.77**	-8.91	13.19**	13.18*	8.34*	11.13*	4.71
	[0.10]	[1.30]	[1.14]	[0.93]	[1.22]	[1.78]	[2.09]	[11.54]	[5.78]	[7.72]	[4.59]	[6.46]	[5.02]
Child age squared	0.08***	0.03	0.04	0.06	0.18***	0.11	0.29***	0.15	-0.74***	-0.82**	-0.45**	-0.60**	-0.43*
	[0.00]	[0.07]	[0.03]	[0.05]	[0.05]	[0.07]	[0.09]	[0.65]	[0.26]	[0.36]	[0.21]	[0.29]	[0.23]
Mother education: Certificate [a]	0.39**	-1.82	2.77	1.33	1.71	-0.43	1.27	-6.31	-6.83*	-7.25	-4.75	-7.24	-5.08
	[0.19]	[1.76]	[1.98]	[1.22]	[1.31]	[2.36]	[2.65]	[7.99]	[3.92]	[5.52]	[3.35]	[4.42]	[3.32]
Mother education: Graduate [a]	0.23	-3.27	0.20	2.32	4.33**	0.56	4.89	-12.68	-9.72*	-7.65	-1.74	-8.52	-6.72
	[0.25]	[2.33]	[2.60]	[1.62]	[1.94]	[2.49]	[3.10]	[10.71]	[5.48]	[7.08]	[4.64]	[6.17]	[4.15]
Number of siblings	-0.20***	0.25	0.03	0.04	0.27	1.94*	2.21*	-1.23	-2.21	-0.02	0.39	-1.38	-0.87
	[0.08]	[0.67]	[0.85]	[0.47]	[0.58]	[1.05]	[1.19]	[3.34]	[1.50]	[2.30]	[1.36]	[1.98]	[1.38]
Living with both parents	-0.51***	5.09***	-2.85*	-0.41	-3.10**	2.19	-0.91	-2.58	2.32	6.34	4.73*	2.31	5.58**
	[0.15]	[1.46]	[1.67]	[0.96]	[1.35]	[2.16]	[2.52]	[6.77]	[3.28]	[5.38]	[2.71]	[3.79]	[2.74]
Second quarter [b]	-0.00	-4.46**	7.12**	2.02	-0.73	1.05	0.32	9.94	-0.73	7.90	2.67	9.00*	9.61**
	[0.22]	[1.94]	[3.01]	[1.29]	[1.51]	[1.82]	[2.25]	[9.74]	[4.26]	[6.55]	[3.17]	[5.27]	[3.85]
Third quarter [b]	-0.10	-6.18***	7.60**	2.24	-0.98	1.96	0.98	14.93	-3.12	4.50	0.13	5.44	9.39**
	[0.23]	[2.02]	[3.09]	[1.37]	[1.68]	[3.51]	[3.82]	[10.14]	[4.38]	[6.74]	[3.28]	[5.43]	[3.93]
Fourth quarter [b]	-0.28	-3.69*	10.51***	2.31*	-1.00	-1.24	-2.25	17.82	-0.63	6.55	1.72	7.72	8.64**
	[0.21]	[2.05]	[2.93]	[1.40]	[1.63]	[1.09]	[1.85]	[11.10]	[4.59]	[6.99]	[3.44]	[5.62]	[4.10]
Monday [c]	0.20	-0.15	1.46	-0.81	3.04*	-1.56	1.48	5.23	2.87	-1.13	3.64	1.02	-1.93
	[0.19]	[1.83]	[2.28]	[1.24]	[1.71]	[2.17]	[2.68]	[4.26]	[2.84]	[4.27]	[2.42]	[3.33]	[2.47]
Tuesday [c]	0.35	0.25	2.69	-1.49	4.01*	-0.01	4.00*	7.94	2.22	-1.54	4.86*	2.54	-0.37
	[0.23]	[2.23]	[2.69]	[1.54]	[2.08]	[1.16]	[2.29]	[5.47]	[3.28]	[4.80]	[2.78]	[3.78]	[2.86]
Wednesday [c]	0.34	0.33	1.65	-1.44	4.20**	-2.95	1.25	10.78**	2.22	0.15	3.75	2.38	-1.50
	[0.23]	[2.24]	[2.65]	[1.53]	[2.02]	[3.54]	[3.96]	[5.05]	[3.14]	[4.63]	[2.65]	[3.63]	[2.72]
Thursday [c]	0.37	-0.33	1.99	-1.02	3.66	-2.11	1.55	7.23	2.94	0.86	4.84*	2.32	-0.31
	[0.26]	[2.52]	[2.87]	[1.73]	[2.36]	[3.20]	[3.85]	[5.06]	[3.21]	[4.88]	[2.76]	[3.77]	[2.88]
Friday [c]	0.60	0.15	4.36	-1.72	7.64**	-5.22	2.43	12.06	6.71	-2.06	9.28*	5.19	-1.22
	[0.46]	[4.41]	[5.08]	[3.02]	[3.88]	[6.10]	[7.02]	[8.24]	[6.10]	[9.21]	[5.17]	[7.11]	[5.36]
Saturday [c]	0.33	-0.65	2.82	-1.62	4.70*	-2.90	1.80	11.12	2.78	-1.30	4.89	3.18	-1.62
	[0.29]	[2.84]	[3.26]	[1.95]	[2.54]	[3.74]	[4.38]	[7.07]	[4.28]	[6.37]	[3.65]	[5.01]	[3.76]
Holidays	-0.23***	0.46	0.20	0.83**	0.43	-0.03	0.40	4.74	0.42	0.28	-1.00	-0.58	1.71*
	[0.08]	[0.58]	[0.93]	[0.42]	[0.55]	[0.74]	[0.92]	[3.12]	[1.03]	[1.56]	[0.87]	[1.18]	[0.88]
Observation	46,496	53,692	41,363	53,687	53,001	53,002	53,001	14,384	18,854	18,849	18,881	18,876	18,742
Number of unique individuals	8,311	8,699	8,109	8,699	8,546	8,546	8,546	3,519	5,503	5,506	5,510	5,509	5,472

Notes: Results are from the FE-IV regression. Coefficient estimates and standard errors are multiplied by 100 for aesthetic purposes. [a], [b], and [c] denotes having year 12 or below qualification, first quarter and Sunday as the base group, respectively. Other variables include local socio-economic background variables, state/territory dummies, and

TUD year dummies. Robust standard errors clustered at the individual level are in parentheses. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A8: Impact of sleep duration on general development and behavioural outcomes - results from POLS and IV models

	POLS	IV	POLS	IV	POLS	IV	POLS	IV	POLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Social development		Emotional development		Physical development		PedsQL Overall		Pro-sociality	
Sleep duration (hour/day)	0.73**	27.08*	3.02***	0.65	0.71**	20.66	1.55***	22.39	1.16***	-1.27
	[0.30]	[15.07]	[0.31]	[13.17]	[0.30]	[14.28]	[0.31]	[14.34]	[0.34]	[12.55]
Observations	45,527	45,966	46,518	46,976	45,544	45,998	43,970	44,394	40,934	41,303
Mean of dep. variable	0.03	0.03	0.01	0.01	0.03	0.03	0.03	0.03	0.00	0.00
F-statistic of IV		20.88		24.09		21.51		21.56		28.43
Hausman test (p value)		0.06		0.88		0.14		0.12		0.84
	Hyperactivity		Emotional symptoms		Conduct		Peer problem		SDQ Overall	
Sleep duration (hour/day)	1.46***	8.46	1.56***	10.81	1.73***	16.95	1.04***	-5.10	2.06***	9.19
	[0.34]	[12.65]	[0.34]	[12.28]	[0.34]	[12.46]	[0.33]	[12.74]	[0.33]	[12.33]
Observations	40,928	41,297	40,931	41,300	40,932	41,301	40,934	41,303	40,921	41,290
Mean of dep. variable	0.04	0.04	0.04	0.05	0.02	0.02	0.03	0.03	0.04	0.04
F-statistic of IV		28.43		28.35		28.31		28.46		28.43
Hausman test (p value)		0.58		0.44		0.21		0.64		0.55

Notes: POLS results are from the regression (1) without controlling for individual FE. IV results from models (1) and (2) without controlling for individual FE. F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration. Other explanatory variables include child age (and its square), child gender, Aboriginal status, low birthweight status, cohort dummy, maternal completed qualification, maternal migration statuses, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A9: Impact of sleep duration on anthropometric and health outcomes - results from POLS and IV models

	POLS	IV	POLS	IV	POLS	IV	POLS	IV	POLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Social development		Emotional development		Physical development		PedsQL Overall		Pro-sociality	
	BMI		Underweight		Overweight		Waist-for-height ratio		Excellent health	
Sleep duration (hour/day)	-1.99***	30.07*	0.24***	-2.11	-0.54***	8.83	-0.06***	1.46**	0.47***	0.45
	[0.35]	[16.77]	[0.07]	[3.23]	[0.13]	[6.12]	[0.01]	[0.72]	[0.14]	[5.76]
Observations	46,966	47,431	47,003	47,468	47,003	47,468	46,867	47,330	54,001	54,524
Mean of dep. variable	0.46	0.46	0.06	0.06	0.22	0.22	0.48	0.48	0.54	0.54
F-statistic of IV		23.04		23.10		23.10		23.07		28.26
Hausman test (p value)		0.04		0.47		0.11		0.02		1.00
	Any ongoing condition		Prescribed medicine		MBS ($1000)		PBS ($1000)		MBS and PBS ($1000)	
Sleep duration (hour/day)	-0.35**	2.16	-0.05	0.32	-0.33*	9.09**	-0.17	-8.03	-0.51**	1.06
	[0.15]	[7.08]	[0.10]	[3.98]	[0.20]	[4.46]	[0.15]	[9.99]	[0.25]	[10.91]
Observations	41,789	42,156	53,996	54,519	53,272	53,783	53,273	53,784	53,272	53,783
Mean of dep. variable	0.40	0.40	0.14	0.14	0.24	0.24	0.03	0.03	0.27	0.27
F-statistic of IV		19.85		28.48		30.10		30.08		30.10
Hausman test (p value)		0.71		0.93		0.02		0.42		0.89

Notes: POLS results are from the regression (1) without controlling for individual FE. IV results from models (1) and (2) without controlling for individual FE. F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration. Other explanatory variables include child age (and its square), child gender, Aboriginal status, low birthweight status, cohort dummy, maternal completed qualification, maternal migration statuses, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A10: Impact of sleep duration on cognitive outcomes - results from POLS and IV models

	POLS	IV	POLS	IV	POLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)
	Matrix reasoning		Reading		Writing	
Sleep duration (hour/day)	-1.45***	18.92	-1.22***	15.04	-1.29***	15.35
	[0.48]	[13.81]	[0.37]	[10.87]	[0.38]	[11.64]
Observations	18,241	18,402	20,124	20,261	20,121	20,260
Mean of dep. variable	0.04	0.03	0.18	0.18	0.20	0.20
F-statistic of IV		28.24		25.72		25.56
Hausman test (p value)		0.13		0.13		0.14
	Spelling		Grammar		Numeracy	
Sleep duration (hour/day)	-0.70**	24.79**	-0.92**	15.56	-1.62***	3.52
	[0.35]	[11.48]	[0.37]	[11.22]	[0.33]	[9.81]
Observations	20,150	20,289	20,146	20,285	20,038	20,176
Mean of dep. variable	0.19	0.19	0.18	0.17	0.23	0.22
F-statistic of IV		25.58		25.61		26.07
Hausman test (p value)		0.01		0.13		0.62

Notes: POLS results are from the regression (1) without controlling for individual FE. IV results from models (1) and (2) without controlling for individual FE. F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration. Other explanatory variables include child age (and its square), child gender, Aboriginal status, low birthweight status, cohort dummy, maternal completed qualification, maternal migration statuses, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A11: Impact of sleep duration on child development – Robustness checks

	Social development	Emotional development	Physical development	PedsQL Overall	Pro-sociality	Hyperactivity	Emotional symptoms	Conduct	Peer problem	SDQ Overall	BMI	Underweight	Overweight
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Panel A: Baseline													
Sleep duration (hour/day)	6.87	17.98*	22.59*	25.51**	-2.23	-2.85	14.25	10.12	-11.79	2.07	20.94**	-1.30	8.17*
	[12.13]	[10.67]	[13.25]	[12.03]	[10.14]	[8.95]	[10.67]	[9.65]	[10.90]	[8.60]	[10.50]	[2.84]	[4.73]
Observations	45,138	46,142	45,133	43,540	40,422	40,415	40,419	40,420	40,422	40,408	46,600	46,638	46,638
Individuals	8,222	8,264	8,210	8,114	7,962	7,960	7,961	7,962	7,962	7,959	8,321	8,324	8,324
F-statistic of IV	21.55	27.68	22.38	23.47	27.34	27.49	27.22	27.29	27.38	27.39	24.46	24.62	24.62
Hausman test (p value)	0.58	0.10	0.06	0.02	0.84	0.73	0.19	0.32	0.26	0.86	0.03	0.63	0.06
Panel B1: Using different instrument - Sunrise time													
Sleep duration (hour/day)	9.62	16.36	22.06	24.88**	7.02	-4.45	17.43*	7.62	-7.47	5.70	18.72*	-2.47	8.33*
	[12.26]	[10.59]	[13.79]	[12.02]	[9.81]	[8.54]	[10.33]	[9.02]	[10.23]	[8.24]	[11.00]	[3.12]	[5.03]
Observations	45,138	46,142	45,133	43,540	40,422	40,415	40,419	40,420	40,422	40,408	46,600	46,638	46,638
Individuals	8,222	8,264	8,210	8,114	7,962	7,960	7,961	7,962	7,962	7,959	8,321	8,324	8,324
F-statistic of IV	21.21	26.96	20.63	23.21	30.05	30.08	29.96	30.01	30.09	29.97	21.38	21.51	21.51
Hausman test (p value)	0.44	0.14	0.08	0.03	0.46	0.58	0.09	0.44	0.45	0.53	0.06	0.41	0.07
Panel B2: Using different instrument - Sunset time													
Sleep duration (hour/day)	3.37	20.02	23.21	26.32	-15.45	-0.58	9.68	13.71	-17.97	-3.09	23.43*	0.01	7.99
	[16.27]	[14.58]	[16.89]	[16.25]	[15.36]	[12.91]	[15.52]	[15.07]	[16.44]	[12.62]	[13.22]	[3.38]	[5.81]
Observations	45,138	46,142	45,133	43,540	40,422	40,415	40,419	40,420	40,422	40,408	46,600	46,638	46,638
Individuals	8,222	8,264	8,210	8,114	7,962	7,960	7,961	7,962	7,962	7,959	8,321	8,324	8,324
F-statistic of IV	11.82	15.50	13.59	12.96	12.75	12.90	12.67	12.72	12.77	12.86	15.57	15.69	15.69
Hausman test (p value)	0.85	0.17	0.13	0.08	0.30	0.95	0.56	0.37	0.24	0.77	0.04	0.99	0.14
Panel C: Excluding individual and household level variables (except child age and its square)													
Sleep duration (hour/day)	6.86	17.01	20.94	24.22**	-2.35	-3.92	12.71	10.05	-11.70	1.19	21.42**	-1.16	8.42*
	[12.04]	[10.57]	[13.06]	[11.84]	[10.06]	[8.91]	[10.51]	[9.57]	[10.81]	[8.54]	[10.48]	[2.81]	[4.73]
Observations	45,259	46,263	45,251	43,658	40,533	40,526	40,530	40,531	40,533	40,519	46,743	46,785	46,785
Individuals	8,246	8,288	8,234	8,138	7,985	7,983	7,984	7,985	7,985	7,982	8,347	8,350	8,350
F-statistic of IV	21.84	27.99	22.68	23.84	27.85	28.00	27.73	27.80	27.89	27.90	24.75	24.95	24.95
Hausman test (p value)	0.58	0.12	0.08	0.03	0.82	0.64	0.24	0.32	0.26	0.94	0.02	0.67	0.05

Notes: Results are from models (1) and (2), unless stated otherwise. F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration, unless stated otherwise. Unless stated

otherwise, other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A11: Impact of sleep duration on child development – Robustness checks (continued)

	Social development	Emotional development	Physical development	PedsQL Overall	Pro-sociality	Hyperactivity	Emotional symptoms	Conduct	Peer problem	SDQ Overall	BMI	Underweight	Overweight
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Panel D1: Adding more variables - Personal care time													
Sleep duration (hour/day)	6.40	16.35*	20.48*	23.50**	-1.92	-2.39	12.55	9.03	-10.20	1.96	18.84**	-1.16	7.34*
	[11.08]	[9.48]	[11.85]	[10.82]	[8.84]	[7.80]	[9.20]	[8.40]	[9.45]	[7.51]	[9.23]	[2.54]	[4.17]
Observations	45,138	46,142	45,133	43,540	40,422	40,415	40,419	40,420	40,422	40,408	46,600	46,638	46,638
Individuals	8,222	8,264	8,210	8,114	7,962	7,960	7,961	7,962	7,962	7,959	8,321	8,324	8,324
F-statistic of IV	28.36	37.69	29.82	30.73	39.35	39.47	39.12	39.21	39.32	39.30	33.29	33.67	33.67
Hausman test (p value)	0.57	0.10	0.07	0.02	0.84	0.74	0.19	0.31	0.27	0.84	0.02	0.63	0.06
Panel D2: Adding more variables - School time													
Sleep duration (hour/day)	8.17	21.27*	26.65*	29.86**	-2.42	-3.01	16.11	10.99	-12.76	2.47	24.94**	-1.71	9.57*
	[14.07]	[12.52]	[15.73]	[14.29]	[11.46]	[10.12]	[12.16]	[10.93]	[12.35]	[9.71]	[12.72]	[3.34]	[5.67]
Observations	45,138	46,142	45,133	43,540	40,422	40,415	40,419	40,420	40,422	40,408	46,600	46,638	46,638
Individuals	8,222	8,264	8,210	8,114	7,962	7,960	7,961	7,962	7,962	7,959	8,321	8,324	8,324
F-statistic of IV	16.35	21.14	16.92	17.98	21.74	21.86	21.65	21.70	21.80	21.80	18.05	18.18	18.18
Hausman test (p value)	0.57	0.09	0.06	0.02	0.84	0.74	0.19	0.33	0.28	0.84	0.02	0.60	0.06
Panel D3: Adding more variables - Physically active time													
Sleep duration (hour/day)	8.85	21.50*	28.15*	31.70**	-2.71	-3.28	17.17	12.10	-13.50	2.69	24.27*	-1.46	9.54*
	[14.89]	[12.95]	[16.58]	[15.32]	[11.90]	[10.49]	[12.66]	[11.39]	[12.86]	[10.09]	[12.78]	[3.36]	[5.74]
Observations	45,138	46,142	45,133	43,540	40,422	40,415	40,419	40,420	40,422	40,408	46,600	46,638	46,638
Individuals	8,222	8,264	8,210	8,114	7,962	7,960	7,961	7,962	7,962	7,959	8,321	8,324	8,324
F-statistic of IV	14.82	19.89	15.61	16.18	20.45	20.62	20.36	20.43	20.52	20.51	17.96	18.03	18.03
Hausman test (p value)	0.56	0.10	0.06	0.02	0.83	0.73	0.18	0.31	0.27	0.83	0.03	0.65	0.06
Panel D4: Adding more variables - Media time													
Sleep duration (hour/day)	7.31	19.00*	23.85*	26.69**	-1.33	-1.95	15.24	10.27	-10.52	3.32	20.26**	-1.41	7.75*
	[12.04]	[10.64]	[13.24]	[12.07]	[10.03]	[8.85]	[10.60]	[9.56]	[10.73]	[8.51]	[10.33]	[2.80]	[4.65]
Observations	45,138	46,142	45,133	43,540	40,422	40,415	40,419	40,420	40,422	40,408	46,600	46,638	46,638
Individuals	8,222	8,264	8,210	8,114	7,962	7,960	7,961	7,962	7,962	7,959	8,321	8,324	8,324
F-statistic of IV	21.90	28.08	22.74	23.74	27.95	28.10	27.83	27.90	27.99	28.00	25.02	25.18	25.18
Hausman test (p value)	0.55	0.08	0.05	0.02	0.91	0.80	0.16	0.31	0.31	0.74	0.03	0.60	0.07

Notes: Results are from models (1) and (2), unless stated otherwise. F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration, unless stated otherwise. Unless stated

otherwise, other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A11: Impact of sleep duration on child development – Robustness checks (continued)

	Social development	Emotional development	Physical development	PedsQL Overall	Pro-sociality	Hyperactivity	Emotional symptoms	Conduct	Peer problem	SDQ Overall	BMI	Underweight	Overweight
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Panel D5: Adding more variables - Corresponding parent's general health (5-point scale indicating if general health is excellent, very good, good, fair or poor)													
Sleep duration (hour/day)	6.57	18.11*	23.07*	25.76**	-2.07	-3.33	16.02	9.98	-9.53	3.00	22.45**	-1.51	8.18*
	[12.09]	[10.70]	[13.24]	[11.99]	[10.65]	[9.40]	[11.27]	[10.09]	[11.36]	[9.04]	[10.75]	[2.87]	[4.78]
Observations	45,020	46,019	45,014	43,424	40,162	40,155	40,159	40,160	40,162	40,148	46,013	46,051	46,051
Individuals	8,216	8,257	8,203	8,108	7,936	7,934	7,935	7,936	7,936	7,933	8,263	8,266	8,266
F-statistic of IV	21.54	27.39	22.46	23.60	24.91	25.06	24.79	24.87	24.96	24.96	23.93	24.11	24.11
Hausman test (p value)	0.60	0.10	0.06	0.02	0.86	0.70	0.16	0.35	0.38	0.78	0.02	0.58	0.06
Panel D6: Adding more variables - Corresponding parent's mental health (K6 mental health scores)													
Sleep duration (hour/day)	5.18	17.24*	22.57*	24.45**	-0.83	-0.63	15.51	9.16	-9.45	4.00	18.17*	-0.73	7.77*
	[11.88]	[10.32]	[12.97]	[11.72]	[10.25]	[9.00]	[10.81]	[9.69]	[10.93]	[8.66]	[9.94]	[2.72]	[4.53]
Observations	44,639	45,620	44,638	43,067	39,938	39,933	39,935	39,936	39,938	39,926	45,722	45,760	45,760
Individuals	8,193	8,234	8,183	8,083	7,926	7,924	7,925	7,926	7,926	7,923	8,250	8,253	8,253
F-statistic of IV	22.07	28.93	23.38	24.15	26.70	26.85	26.58	26.65	26.75	26.75	26.35	26.53	26.53
Hausman test (p value)	0.67	0.11	0.06	0.02	0.95	0.92	0.16	0.37	0.37	0.68	0.04	0.77	0.06
Panel D7: Adding more variables - Corresponding parent's work status (full-time employed, part-time employed, or unemployed)													
Sleep duration (hour/day)	6.60	17.09	21.88*	24.74**	-2.34	-2.95	13.37	10.04	-11.68	1.76	20.90**	-1.34	8.14*
	[12.06]	[10.55]	[13.06]	[11.90]	[10.11]	[8.92]	[10.58]	[9.61]	[10.87]	[8.57]	[10.39]	[2.81]	[4.68]
Observations	45,094	46,096	45,087	43,495	40,375	40,368	40,372	40,373	40,375	40,361	46,549	46,587	46,587
Individuals	8,218	8,260	8,206	8,109	7,956	7,954	7,955	7,956	7,956	7,953	8,317	8,320	8,320
F-statistic of IV	21.80	28.02	22.82	23.73	27.58	27.72	27.45	27.52	27.62	27.62	25.01	25.16	25.16
Hausman test (p value)	0.60	0.12	0.07	0.02	0.83	0.72	0.22	0.32	0.26	0.88	0.02	0.62	0.06
Panel D8: Adding more variables - Household income (weekly income, measured in 2004 price)													
Sleep duration (hour/day)	6.71	17.88*	22.56*	25.41**	-2.36	-2.74	13.95	10.07	-12.02	1.91	21.09**	-1.37	8.35*
	[12.13]	[10.65]	[13.24]	[12.02]	[10.15]	[8.95]	[10.65]	[9.65]	[10.91]	[8.60]	[10.53]	[2.84]	[4.75]
Observations	45,133	46,137	45,128	43,535	40,415	40,408	40,412	40,413	40,415	40,401	46,592	46,630	46,630
Individuals	8,222	8,264	8,210	8,114	7,960	7,958	7,959	7,960	7,960	7,957	8,320	8,323	8,323
F-statistic of IV	21.57	27.72	22.40	23.48	27.37	27.52	27.25	27.32	27.41	27.42	24.42	24.58	24.58
Hausman test (p value)	0.59	0.10	0.06	0.02	0.83	0.74	0.20	0.32	0.25	0.87	0.02	0.61	0.06

Notes: Results are from models (1) and (2), unless stated otherwise. F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration, unless stated otherwise. Unless stated

otherwise, other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A11: Impact of sleep duration on child development – Robustness checks (continued)

	Social development	Emotional development	Physical development	PedsQL Overall	Pro-sociality	Hyperactivity	Emotional symptoms	Conduct	Peer problem	SDQ Overall	BMI	Underweight	Overweight
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Panel E1: Controlling for weather conditions on TUD date - Daily maximum temperature (and its square) and precipitation													
Sleep duration (hour/day)	21.58	24.40**	26.82*	37.53**	4.77	-8.45	28.65**	7.61	-0.86	8.62	17.07	0.76	9.75*
	[14.90]	[12.30]	[14.94]	[15.64]	[11.86]	[10.63]	[13.54]	[11.04]	[12.15]	[10.19]	[11.63]	[3.21]	[5.60]
Observations	45,138	46,142	45,133	43,540	40,422	40,415	40,419	40,420	40,422	40,408	46,600	46,638	46,638
Individuals	8,222	8,264	8,210	8,114	7,962	7,960	7,961	7,962	7,962	7,959	8,321	8,324	8,324
F-statistic of IV	15.40	21.25	17.23	16.03	19.73	19.74	19.70	19.70	19.83	19.71	17.59	17.74	17.74
Hausman test (p value)	0.12	0.04	0.05	0.00	0.68	0.40	0.02	0.52	0.93	0.42	0.11	0.83	0.05
Panel E2: Controlling for cumulative weather conditions in the 365 days before the survey date - Number of days with daily maximum temperature exceeding given thresholds and number of rainy days													
Sleep duration (hour/day)	9.28	23.44**	23.97**	29.88**	-2.75	2.33	12.37	11.03	-2.28	5.98	20.86**	-2.16	8.48*
	[11.02]	[10.37]	[12.14]	[11.68]	[9.23]	[8.02]	[9.51]	[8.47]	[9.69]	[7.81]	[9.96]	[2.69]	[4.52]
Observations	41,577	42,423	41,538	40,162	36,554	36,547	36,551	36,552	36,554	36,540	42,764	42,792	42,792
Individuals	8,063	8,110	8,057	7,958	7,801	7,799	7,801	7,801	7,801	7,798	8,165	8,166	8,166
F-statistic of IV	25.70	30.99	26.82	26.60	32.06	32.21	31.92	31.99	32.10	32.11	27.53	27.65	27.65
Hausman test (p value)	0.41	0.02	0.03	0.00	0.79	0.79	0.21	0.20	0.81	0.47	0.02	0.41	0.04
Panel F: Reduced form													
Daily daylight duration (hour)	-0.44	-1.30*	-1.50*	-1.75**	0.17	0.21	-1.06	-0.75	0.88	-0.15	-1.44**	0.09	-0.56*
	[0.78]	[0.74]	[0.82]	[0.75]	[0.76]	[0.67]	[0.77]	[0.71]	[0.79]	[0.64]	[0.66]	[0.19]	[0.31]
Observations	45,138	46,142	45,133	43,540	40,422	40,415	40,419	40,420	40,422	40,408	46,600	46,638	46,638
Individuals	8,222	8,264	8,210	8,114	7,962	7,960	7,961	7,962	7,962	7,959	8,321	8,324	8,324

Notes: Results are from models (1) and (2), unless stated otherwise. F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration, unless stated otherwise. Unless stated otherwise, other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A11: Impact of sleep duration on child development – Robustness checks (continued)

	Waist-for-height ratio	Excellent health	Any ongoing condition	Prescribed medicine	MBS ($1000)	PBS ($1000)	MBS and PBS ($1000)	MR	Reading	Writing	Spelling	Grammar	Numeracy
	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
Panel A: Baseline													
Sleep duration (hour/day)	0.82	-0.69	3.10	-2.47	9.83*	-7.08	2.75	15.72	5.41	-0.43	10.58**	3.41	-1.23
	[0.53]	[5.87]	[5.47]	[4.02]	[5.21]	[8.62]	[9.79]	[10.42]	[6.11]	[9.15]	[5.17]	[7.14]	[5.42]
Observations	46,496	53,692	41,363	53,687	53,001	53,002	53,001	14,384	18,854	18,849	18,881	18,876	18,742
Individuals	8,311	8,699	8,109	8,699	8,546	8,546	8,546	3,519	5,503	5,506	5,510	5,509	5,472
F-statistic of IV	24.84	25.48	29.43	25.64	26.91	26.85	26.91	30.20	26.75	26.35	25.79	25.78	25.52
Hausman test (p value)	0.10	0.87	0.54	0.53	0.04	0.41	0.73	0.11	0.39	1.00	0.03	0.67	0.80
Panel B1: Using different instrument - Sunrise time													
Sleep duration (hour/day)	1.43**	-1.87	-2.76	-0.13	11.64*	-0.69	10.95	14.85	7.58	5.94	11.13**	0.44	-1.11
	[0.62]	[6.33]	[5.89]	[4.46]	[7.05]	[4.74]	[8.40]	[10.16]	[6.23]	[9.13]	[5.20]	[7.35]	[5.41]
Observations	46,496	53,692	41,363	53,687	53,001	53,002	53,001	14,384	18,854	18,849	18,881	18,876	18,742
Individuals	8,311	8,699	8,109	8,699	8,546	8,546	8,546	3,519	5,503	5,506	5,510	5,509	5,472
F-statistic of IV	21.67	20.41	24.73	20.53	21.52	21.46	21.52	33.36	25.74	26.20	25.14	25.17	24.89
Hausman test (p value)	0.01	0.73	0.67	0.96	0.07	0.93	0.15	0.12	0.23	0.48	0.02	1.00	0.82
Panel B2: Using different instrument - Sunset time													
Sleep duration (hour/day)	0.13	0.53	9.46	-4.90	7.95	-13.70	-5.74	16.96	2.72	-8.58	9.88	7.17	-1.39
	[0.62]	[7.31]	[6.83]	[4.98]	[5.48]	[13.33]	[14.11]	[13.44]	[7.75]	[12.02]	[6.59]	[9.06]	[6.97]
Observations	46,496	53,692	41,363	53,687	53,001	53,002	53,001	14,384	18,854	18,849	18,881	18,876	18,742
Individuals	8,311	8,699	8,109	8,699	8,546	8,546	8,546	3,519	5,503	5,506	5,510	5,509	5,472
F-statistic of IV	15.80	15.92	20.50	16.02	16.86	16.82	16.86	16.22	16.47	15.56	15.60	15.56	15.46
Hausman test (p value)	0.83	0.97	0.13	0.30	0.11	0.29	0.70	0.17	0.75	0.49	0.11	0.45	0.83
Panel C: Excluding individual and household level variables (except child age and its square)													
Sleep duration (hour/day)	0.86	-1.05	3.50	-2.73	9.83*	-7.27	2.56	14.45	5.36	-0.32	10.57**	3.54	-1.33
	[0.53]	[5.88]	[5.48]	[4.04]	[5.21]	[8.73]	[9.88]	[10.36]	[6.19]	[9.27]	[5.21]	[7.21]	[5.49]
Observations	46,641	53,831	41,468	53,826	53,158	53,159	53,158	14,432	18,905	18,901	18,933	18,928	18,791
Individuals	8,337	8,727	8,132	8,727	8,573	8,573	8,573	3,530	5,518	5,521	5,525	5,524	5,486
F-statistic of IV	25.24	25.40	29.42	25.55	26.97	26.91	26.97	30.23	26.07	25.91	25.39	25.38	24.90
Hausman test (p value)	0.08	0.82	0.49	0.48	0.04	0.40	0.75	0.14	0.40	0.99	0.03	0.66	0.79

Notes: Results are from models (1) and (2), unless stated otherwise. F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration, unless stated otherwise. Unless stated otherwise, other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A11: Impact of sleep duration on child development – Robustness checks (continued)

	Waist-for-height ratio	Excellent health	Any ongoing condition	Prescribed medicine	MBS ($1000)	PBS ($1000)	MBS and PBS ($1000)	MR	Reading	Writing	Spelling	Grammar	Numeracy
	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
Panel D1: Adding more variables - Personal care time													
Sleep duration (hour/day)	0.75	-0.46	2.74	-2.11	7.91*	-6.14	1.78	14.86	4.92	-0.42	9.33**	3.05	-1.00
	[0.48]	[4.85]	[4.97]	[3.32]	[4.15]	[7.37]	[8.30]	[9.74]	[5.42]	[8.05]	[4.45]	[6.29]	[4.88]
Observations	46,496	53,692	41,363	53,687	53,001	53,002	53,001	14,384	18,854	18,849	18,881	18,876	18,742
Individuals	8,311	8,699	8,109	8,699	8,546	8,546	8,546	3,519	5,503	5,506	5,510	5,509	5,472
F-statistic of IV	32.76	40.48	38.29	40.73	42.25	42.13	42.25	38.03	36.21	36.52	35.86	35.71	33.83
Hausman test (p value)	0.09	0.89	0.56	0.50	0.05	0.40	0.81	0.10	0.37	1.00	0.03	0.67	0.84
Panel D2: Adding more variables - School time													
Sleep duration (hour/day)	0.97	-0.74	3.60	-2.96	11.05*	-8.06	2.99	17.33	6.08	-0.43	11.73**	3.39	-1.26
	[0.63]	[6.80]	[6.35]	[4.68]	[6.10]	[9.82]	[11.16]	[11.58]	[6.80]	[10.21]	[5.87]	[7.98]	[6.06]
Observations	46,496	53,692	41,363	53,687	53,001	53,002	53,001	14,384	18,854	18,849	18,881	18,876	18,742
Individuals	8,311	8,699	8,109	8,699	8,546	8,546	8,546	3,519	5,503	5,506	5,510	5,509	5,472
F-statistic of IV	18.56	19.27	22.32	19.39	20.50	20.46	20.50	25.00	21.90	21.34	20.88	20.85	20.65
Hausman test (p value)	0.09	0.88	0.54	0.51	0.05	0.41	0.74	0.11	0.38	1.00	0.03	0.70	0.82
Panel D3: Adding more variables - Physically active time													
Sleep duration (hour/day)	0.93	-0.02	3.48	-3.38	11.90*	-8.91	3.00	15.99	5.81	-0.53	11.66**	3.67	-1.47
	[0.64]	[7.33]	[6.60]	[5.06]	[6.61]	[10.82]	[12.19]	[10.63]	[6.76]	[10.23]	[5.87]	[8.00]	[6.00]
Observations	46,496	53,692	41,363	53,687	53,001	53,002	53,001	14,384	18,854	18,849	18,881	18,876	18,742
Individuals	8,311	8,699	8,109	8,699	8,546	8,546	8,546	3,519	5,503	5,506	5,510	5,509	5,472
F-statistic of IV	18.30	16.63	20.85	16.73	18.06	18.01	18.06	30.75	22.63	21.73	21.21	21.15	21.52
Hausman test (p value)	0.11	0.95	0.56	0.49	0.04	0.41	0.76	0.11	0.39	0.99	0.03	0.68	0.79
Panel D4: Adding more variables - Media time													
Sleep duration (hour/day)	0.77	0.14	2.85	-2.55	9.21*	-6.43	2.79	15.72	5.29	-0.39	10.48**	3.24	-1.36
	[0.52]	[5.65]	[5.43]	[3.88]	[4.98]	[7.91]	[9.11]	[10.48]	[6.11]	[9.18]	[5.17]	[7.15]	[5.42]
Observations	46,496	53,692	41,363	53,687	53,001	53,002	53,001	14,384	18,854	18,849	18,881	18,876	18,742
Individuals	8,311	8,699	8,109	8,699	8,546	8,546	8,546	3,519	5,503	5,506	5,510	5,509	5,472
F-statistic of IV	25.42	27.44	29.82	27.60	28.88	28.81	28.88	29.88	26.68	26.20	25.67	25.64	25.45
Hausman test (p value)	0.11	0.98	0.56	0.50	0.05	0.42	0.71	0.11	0.40	1.00	0.03	0.69	0.78

Notes: Results are from models (1) and (2), unless stated otherwise. F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration, unless stated otherwise. Unless stated otherwise, other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A11: Impact of sleep duration on child development – Robustness checks (continued)

	Waist-for-height ratio	Excellent health	Any ongoing condition	Prescribed medicine	MBS ($1000)	PBS ($1000)	MBS and PBS ($1000)	MR	Reading	Writing	Spelling	Grammar	Numeracy
	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
Panel D5: Adding more variables - Corresponding parent's general health (5-point scale indicating if general health is excellent, very good, good, fair or poor)													
Sleep duration (hour/day)	0.82	-1.12	3.26	-2.93	10.61**	-7.25	3.37	15.19	5.50	0.21	11.48**	3.01	-0.65
	[0.54]	[5.96]	[5.53]	[4.11]	[5.34]	[8.79]	[9.98]	[10.81]	[6.28]	[9.29]	[5.37]	[7.33]	[5.56]
Observations	45,915	53,031	40,904	53,026	52,334	52,335	52,334	14,236	18,657	18,647	18,679	18,674	18,548
Individuals	8,252	8,639	8,062	8,639	8,483	8,483	8,483	3,491	5,453	5,454	5,458	5,457	5,423
F-statistic of IV	24.20	24.69	29.23	24.84	26.35	26.29	26.35	28.12	25.53	24.97	24.45	24.45	24.34
Hausman test (p value)	0.10	0.82	0.52	0.46	0.03	0.41	0.69	0.13	0.39	0.95	0.02	0.72	0.90
Panel D6: Adding more variables - Corresponding parent's mental health (K6 mental health scores)													
Sleep duration (hour/day)	0.73	0.04	3.84	-2.53	10.46**	-2.69	7.77	15.37	5.46	1.36	10.66**	3.42	-0.09
	[0.50]	[5.77]	[5.41]	[3.96]	[5.17]	[4.66]	[6.82]	[10.54]	[6.11]	[9.17]	[5.12]	[7.10]	[5.35]
Observations	45,622	52,665	40,649	52,659	51,982	51,983	51,982	14,076	18,552	18,542	18,574	18,569	18,443
Individuals	8,240	8,621	8,050	8,621	8,469	8,469	8,469	3,482	5,451	5,452	5,456	5,455	5,420
F-statistic of IV	27.02	26.41	30.92	26.67	28.27	28.21	28.27	30.33	27.31	26.85	26.29	26.28	26.52
Hausman test (p value)	0.12	0.97	0.44	0.51	0.03	0.58	0.20	0.12	0.38	0.85	0.03	0.66	0.97
Panel D7: Adding more variables - Corresponding parent's work status (full-time employed, part-time employed, or unemployed)													
Sleep duration (hour/day)	0.85	-0.77	3.27	-2.21	10.36**	-7.35	3.02	15.11	5.70	-0.52	10.50**	3.12	-1.13
	[0.52]	[5.91]	[5.46]	[4.05]	[5.25]	[8.98]	[10.11]	[10.36]	[6.21]	[9.26]	[5.23]	[7.21]	[5.49]
Observations	46,445	53,637	41,334	53,632	52,939	52,940	52,939	14,381	18,821	18,818	18,850	18,845	18,711
Individuals	8,307	8,696	8,108	8,696	8,543	8,543	8,543	3,519	5,488	5,492	5,496	5,495	5,458
F-statistic of IV	25.42	25.17	29.65	25.33	26.76	26.71	26.76	30.26	26.09	25.84	25.28	25.27	25.04
Hausman test (p value)	0.08	0.86	0.51	0.57	0.03	0.41	0.72	0.12	0.37	0.99	0.03	0.70	0.82
Panel D8: Adding more variables - Household income (weekly income, measured in 2004 price)													
Sleep duration (hour/day)	0.83	-0.59	3.15	-2.46	9.86*	-7.09	2.78	15.50	5.51	-0.44	10.58**	3.45	-1.20
	[0.53]	[5.87]	[5.47]	[4.02]	[5.21]	[8.63]	[9.80]	[10.35]	[6.09]	[9.12]	[5.15]	[7.11]	[5.40]
Observations	46,488	53,687	41,360	53,682	52,996	52,997	52,996	14,380	18,852	18,847	18,879	18,874	18,740
Individuals	8,310	8,699	8,109	8,699	8,545	8,545	8,545	3,518	5,503	5,506	5,510	5,509	5,472
F-statistic of IV	24.81	25.47	29.46	25.62	26.91	26.85	26.91	30.57	26.95	26.55	25.98	25.97	25.71
Hausman test (p value)	0.09	0.88	0.53	0.53	0.04	0.41	0.73	0.11	0.38	1.00	0.03	0.67	0.80

Notes: Results are from models (1) and (2), unless stated otherwise. F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration, unless stated otherwise. Unless stated

otherwise, other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A11: Impact of sleep duration on child development – Robustness checks (continued)

	Waist-for-height ratio	Excellent health	Any ongoing condition	Prescribed medicine	MBS ($1000)	PBS ($1000)	MBS and PBS ($1000)	MR	Reading	Writing	Spelling	Grammar	Numeracy
	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
Panel E1: Controlling for weather conditions on TUD date - Daily maximum temperature (and its square) and precipitation													
Sleep duration (hour/day)	0.87	2.41	-3.03	-2.91	11.36**	-10.89	0.49	17.08	6.47	-0.05	9.63*	-0.45	-4.20
	[0.60]	[6.37]	[6.32]	[4.42]	[5.40]	[12.87]	[13.64]	[11.73]	[6.71]	[9.87]	[5.77]	[7.84]	[6.06]
Observations	46,496	53,692	41,363	53,687	53,001	53,002	53,001	14,384	18,854	18,849	18,881	18,876	18,742
Individuals	8,311	8,699	8,109	8,699	8,546	8,546	8,546	3,519	5,503	5,506	5,510	5,509	5,472
F-statistic of IV	18.43	20.31	20.77	20.38	21.54	21.42	21.54	22.85	22.63	21.29	20.14	20.41	21.66
Hausman test (p value)	0.12	0.74	0.66	0.50	0.02	0.39	0.94	0.12	0.34	0.97	0.08	0.91	0.47
Panel E2: Controlling for cumulative weather conditions in the 365 days before the survey date - Number of days with daily maximum temperature exceeding given thresholds and number of rainy days													
Sleep duration (hour/day)	0.94*	5.84	2.96	-3.70	6.98	-2.05	4.93	14.51	5.51	-0.81	10.95**	3.72	-1.93
	[0.50]	[5.84]	[5.48]	[3.94]	[4.70]	[5.16]	[7.07]	[10.43]	[6.22]	[9.18]	[5.22]	[7.18]	[5.55]
Observations	42,681	45,119	41,363	45,113	44,584	44,585	44,584	14,384	18,854	18,849	18,881	18,876	18,742
Individuals	8,150	8,288	8,109	8,287	8,159	8,159	8,159	3,519	5,503	5,506	5,510	5,509	5,472
F-statistic of IV	28.84	27.28	29.43	27.66	27.99	27.99	27.99	29.71	25.62	25.89	25.39	25.39	24.18
Hausman test (p value)	0.04	0.34	0.55	0.33	0.12	0.71	0.44	0.14	0.39	0.96	0.02	0.64	0.71
Panel F: Reduced form													
Daily daylight duration (hour)	-0.06	0.05	-0.25	0.17	-0.71**	0.51	-0.20	-2.69	-0.60	0.05	-1.15**	-0.37	0.13
	[0.03]	[0.41]	[0.43]	[0.28]	[0.35]	[0.62]	[0.71]	[1.70]	[0.67]	[1.00]	[0.51]	[0.78]	[0.59]
Observations	46,496	53,692	41,363	53,687	53,001	53,002	53,001	14,384	18,854	18,849	18,881	18,876	18,742
Individuals	8,311	8,699	8,109	8,699	8,546	8,546	8,546	3,519	5,503	5,506	5,510	5,509	5,472

Notes: Results are from models (1) and (2), unless stated otherwise. F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration, unless stated otherwise. Unless stated otherwise, other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A12: Non-linear impact of sleep duration – FE results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Social development	Emotional development	Physical development	PedsQL Overall	Pro-sociality	Hyperactivity	Emotional symptoms	Conduct	Peer problem
Sleep duration (hour/day)	1.47	0.57	1.84*	1.79*	-0.03	0.08	2.51**	-0.55	1.28
	[0.97]	[0.96]	[0.97]	[0.92]	[1.06]	[0.93]	[1.14]	[0.98]	[1.07]
Sleep duration squared	-0.07	0.04	-0.12**	-0.07	-0.01	0.01	-0.10	0.07	-0.06
	[0.05]	[0.05]	[0.05]	[0.05]	[0.06]	[0.05]	[0.06]	[0.06]	[0.06]
Observations	45,141	46,145	45,135	43,542	40,425	40,418	40,422	40,423	40,425
Individuals	8,223	8,265	8,211	8,115	7,963	7,961	7,962	7,963	7,963
	SDQ Overall	BMI	Underweight	Overweight	Waist-for-height ratio	Excellent health	Any ongoing condition	Prescribed medicine	MBS ($1000)
Sleep duration (hour/day)	0.92	0.15	0.22	-0.11	0.05	0.57	-0.82	-0.09	-1.38***
	[0.88]	[0.85]	[0.22]	[0.39]	[0.04]	[0.47]	[0.55]	[0.35]	[0.38]
Sleep duration squared	-0.02	-0.03	-0.01	-0.00	-0.00	-0.01	0.03	0.01	0.06***
	[0.05]	[0.05]	[0.01]	[0.02]	[0.00]	[0.02]	[0.03]	[0.02]	[0.02]
Observations	40,411	46,605	46,643	46,643	46,501	53,699	41,368	53,694	53,008
Individuals	7,960	8,322	8,325	8,325	8,312	8,700	8,110	8,700	8,547
	PBS ($1000)	MBS and PBS ($1000)	MR	Reading	Writing	Spelling	Grammar	Numeracy	
Sleep duration (hour/day)	0.69	-0.69	-0.57	0.76	-0.19	-0.42	-1.65	-0.41	
	[0.71]	[0.76]	[1.49]	[0.90]	[1.14]	[0.65]	[1.06]	[0.76]	
Sleep duration squared	-0.05	0.01	0.02	-0.03	-0.01	0.04	0.12**	0.03	
	[0.06]	[0.06]	[0.09]	[0.05]	[0.07]	[0.04]	[0.06]	[0.04]	
Observations	53,009	53,008	14,384	18,854	18,849	18,881	18,876	18,742	
Individuals	8,547	8,547	3,519	5,503	5,506	5,510	5,509	5,472	

Notes: Results are from FE regression (1). Other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A13: Heterogenous impact of sleep duration by gender

	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Social development		Emotional development		Physical development		PedsQL Overall		Pro-sociality		Hyperactivity		Emotional symptoms	
Estimator	FE	FE	FE	FE	FE-IV	FE	FE-IV	FE	FE	FE	FE	FE	FE	FE-IV
Sleep duration (hour/day)	0.37	-0.01	1.73***	0.62**	33.58*	-0.37	29.42*	0.03	-0.00	-0.34	0.41	0.11	1.50***	25.86
	[0.33]	[0.33]	[0.32]	[0.31]	[19.57]	[0.33]	[17.20]	[0.31]	[0.32]	[0.36]	[0.29]	[0.32]	[0.36]	[17.17]
Observations	22,207	22,931	22,581	23,561	22,058	23,075	21,361	22,179	19,783	20,639	19,784	20,631	19,785	20,634
Individuals	4,028	4,194	4,046	4,218	4,019	4,191	3,973	4,141	3,902	4,060	3,902	4,058	3,902	4,059
Mean of dep. variable	0.04	0.03	-0.01	0.04	0.02	0.05	0.02	0.05	0.18	-0.17	0.26	-0.16	-0.01	0.10
F-statistic of IV					11.84		12.09							11.51
Hausman test (p value)					0.05		0.06							0.09
	Conduct		Peer problem		SDQ Overall		BMI		Underweight		Overweight		Waist-for-height ratio	
Estimator	FE	FE	FE-IV	FE	FE	FE	FE	FE-IV	FE	FE	FE	FE-IV	FE	FE
Sleep duration (hour/day)	0.86***	0.36	-32.07**	-0.10	0.95***	0.00	-0.45	36.41**	0.08	0.01	-0.31**	18.44**	-0.01	-0.01
	[0.31]	[0.35]	[15.60]	[0.36]	[0.27]	[0.30]	[0.28]	[17.95]	[0.08]	[0.08]	[0.13]	[8.57]	[0.01]	[0.02]
Observations	19,783	20,637	19,787	20,635	19,782	20,626	22,772	23,828	22,788	23,850	22,788	23,850	22,761	23,735
Individuals	3,902	4,060	3,902	4,060	3,902	4,057	4,071	4,250	4,071	4,253	4,071	4,253	4,068	4,243
Mean of dep. variable	0.11	-0.06	0.10	-0.04	0.20	-0.10	0.41	0.52	0.06	0.06	0.23	0.21	0.48	0.48
F-statistic of IV			15.82					11.20				11.49		
Hausman test (p value)			0.01					0.01				0.00		

Notes: FE results are from the regression (1) while FE-IV results from models (1) and (2). F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration. Other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A13: Heterogenous impact of sleep duration by gender (continued)

	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Excellent health		Any ongoing condition		Prescribed medicine		MBS ($1000)		PBS ($1000)		MBS and PBS ($1000)	
Estimator	FE	FE	FE	FE	FE-IV	FE	FE-IV	FE	FE	FE	FE-IV	FE
Sleep duration (hour/day)	0.47***	0.10	-0.19	-0.31	-8.43	0.20	13.42*	0.01	-0.06	-0.58	14.16	-0.58
	[0.17]	[0.17]	[0.17]	[0.19]	[5.56]	[0.13]	[7.91]	[0.12]	[0.06]	[0.73]	[8.63]	[0.73]
Observations	26,279	27,413	20,272	21,091	26,280	27,407	25,875	27,126	25,876	27,126	25,875	27,126
Individuals	4,262	4,437	3,961	4,148	4,262	4,437	4,177	4,369	4,177	4,369	4,177	4,369
Mean of dep. variable	0.56	0.53	0.40	0.40	0.12	0.15	0.24	0.25	0.02	0.04	0.26	0.28
F-statistic of IV					14.51		16.31				16.31	
Hausman test (p value)					0.10		0.06				0.07	
	Matrix reasoning		Reading		Writing		Spelling		Grammar		Numeracy	
Estimator	FE	FE	FE-IV	FE	FE	FE-IV	FE-IV	FE-IV	FE	FE-IV	FE	FE
Sleep duration (hour/day)	-0.04	-0.30	13.69*	0.42	-0.40	32.99	10.23	34.67**	-0.00	24.13	0.13	0.16
	[0.52]	[0.48]	[8.02]	[0.30]	[0.41]	[21.36]	[6.31]	[16.65]	[0.34]	[16.47]	[0.26]	[0.27]
Observations	6,987	7,397	9,273	9,581	9,280	9,569	9,294	9,587	9,296	9,580	9,206	9,536
Individuals	1,700	1,819	2,710	2,793	2,719	2,787	2,722	2,788	2,722	2,787	2,689	2,783
Mean of dep. variable	0.15	0.02	0.26	0.08	0.37	0.04	0.26	0.10	0.29	0.06	0.16	0.26
F-statistic of IV			16.22			7.78	15.91	7.02		7.04		
Hausman test (p value)			0.06			0.06	0.07	0.00		0.10		

Notes: FE results are from the regression (1) while FE-IV results from models (1) and (2). F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration. Other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A14: Heterogenous impact of sleep duration by age

	Young	Old	Young	Old	Young	Old	Young	Old	Young	Old	Young	Old	Young	Old
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Social development		Emotional development		Physical development		PedsQL Overall		Pro-sociality		Hyperactivity		Emotional symptoms	
Estimator	FE	FE-IV	FE	FE-IV	FE	FE-IV	FE	FE-IV	FE	FE	FE	FE	FE	FE-IV
Sleep duration (hour/day)	-0.01	25.68	0.60**	38.83**	-0.15	33.70*	0.02	46.81**	0.08	0.07	0.26	0.08	0.39	27.16*
	[0.24]	[15.85]	[0.24]	[16.76]	[0.23]	[18.45]	[0.22]	[19.09]	[0.25]	[0.41]	[0.25]	[0.34]	[0.26]	[15.85]
Observations	22,909	21,427	23,083	22,292	22,694	21,665	21,851	20,896	20,262	20,160	20,258	20,157	20,260	19,381
Individuals	7,307	6,637	7,409	6,714	7,313	6,648	7,103	6,554	6,813	7,305	6,811	7,304	6,811	6,526
Mean of dep. variable	0.13	-0.05	-0.01	0.04	0.05	0.02	0.08	0.00	-0.12	0.12	-0.03	0.12	0.13	-0.03
F-statistic of IV		14.56		15.13		15.50		14.24						13.56
Hausman test (p value)		0.08		0.01		0.04		0.00						0.07
	Conduct		Peer problem		SDQ Overall		BMI		Underweight		Overweight		Waist-for-height ratio	
Estimator	FE	FE	FE	FE	FE	FE-IV	FE-IV	FE	FE	FE	FE-IV	FE	FE	FE-IV
Sleep duration (hour/day)	0.47	0.40	0.01	0.24	0.36	22.06*	43.57	-0.46*	0.06	0.08	23.09	-0.16	-0.01	0.96*
	[0.29]	[0.34]	[0.27]	[0.44]	[0.23]	[12.28]	[29.52]	[0.26]	[0.07]	[0.09]	[14.54]	[0.14]	[0.01]	[0.58]
Observations	20,260	20,160	20,262	20,160	20,252	19,377	23,008	23,231	23,385	23,253	23,024	23,253	23,281	22,432
Individuals	6,812	7,305	6,812	7,305	6,810	6,524	7,124	7,510	7,488	7,512	7,127	7,512	7,471	6,716
Mean of dep. variable	-0.22	0.26	0.02	0.04	-0.06	0.15	0.40	0.52	0.05	0.06	0.20	0.25	0.50	0.45
F-statistic of IV						13.70	4.36				4.32			17.92
Hausman test (p value)						0.05	0.03				0.01			0.07

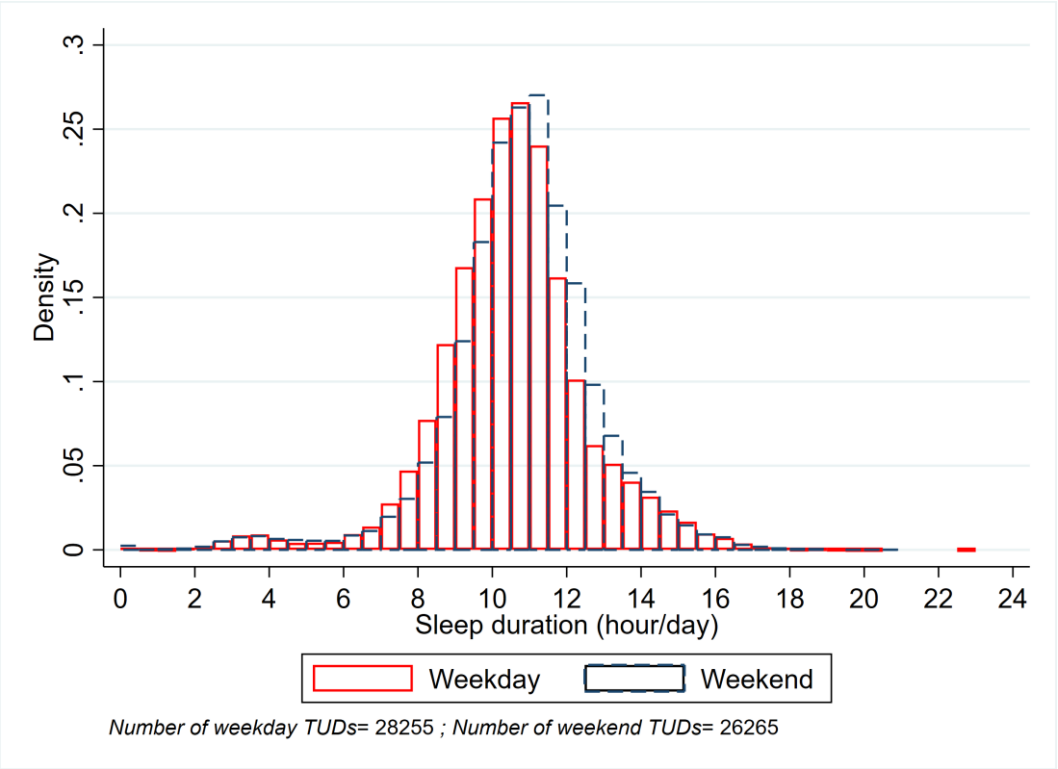
Notes: FE results are from the regression (1) while FE-IV results from models (1) and (2). F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration. Other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Appendix Table A14: Heterogenous impact of sleep duration by age (continued)

	Young	Old	Young	Old	Young	Old	Young	Old	Young	Old	Young	Old
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Excellent health		Any ongoing condition		Prescribed medicine		MBS ($1000)		PBS ($1000)		MBS and PBS ($1000)	
Estimator	FE-IV	FE-IV	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE
Sleep duration (hour/day)	-29.25	13.83**	-0.34**	-0.09	-0.03	0.26**	-0.22	-0.28	0.01	0.09	-0.21	-0.18
	[21.94]	[6.37]	[0.14]	[0.24]	[0.11]	[0.13]	[0.29]	[0.19]	[0.03]	[0.11]	[0.29]	[0.22]
Observations	26,457	26,013	20,965	20,398	26,899	26,788	27,308	25,693	27,308	25,694	27,308	25,693
Individuals	7,230	6,931	7,083	7,405	7,675	7,709	7,628	7,603	7,628	7,603	7,628	7,603
Mean of dep. variable	0.58	0.51	0.30	0.50	0.12	0.15	0.23	0.26	0.02	0.04	0.24	0.30
F-statistic of IV	3.57	26.10										
Hausman test (p value)	0.05	0.02										
	Matrix reasoning		Reading		Writing		Spelling		Grammar		Numeracy	
Estimator	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE
Sleep duration (hour/day)	-0.55*	0.17	0.22	-0.48	-0.30	-0.49	0.09	0.44	0.38	-0.49	0.02	-0.08
	[0.30]	[0.49]	[0.25]	[0.44]	[0.29]	[0.81]	[0.17]	[0.37]	[0.26]	[0.58]	[0.22]	[0.36]
Observations	7,569	6,815	9,544	9,310	9,534	9,315	9,550	9,331	9,546	9,330	9,520	9,222
Individuals	3,317	3,203	3,284	5,215	3,277	5,213	3,277	5,220	3,276	5,219	3,280	5,171
Mean of dep. variable	0.06	0.11	-0.33	0.68	-0.24	0.66	-0.37	0.74	-0.27	0.63	-0.34	0.78
F-statistic of IV												
Hausman test (p value)												

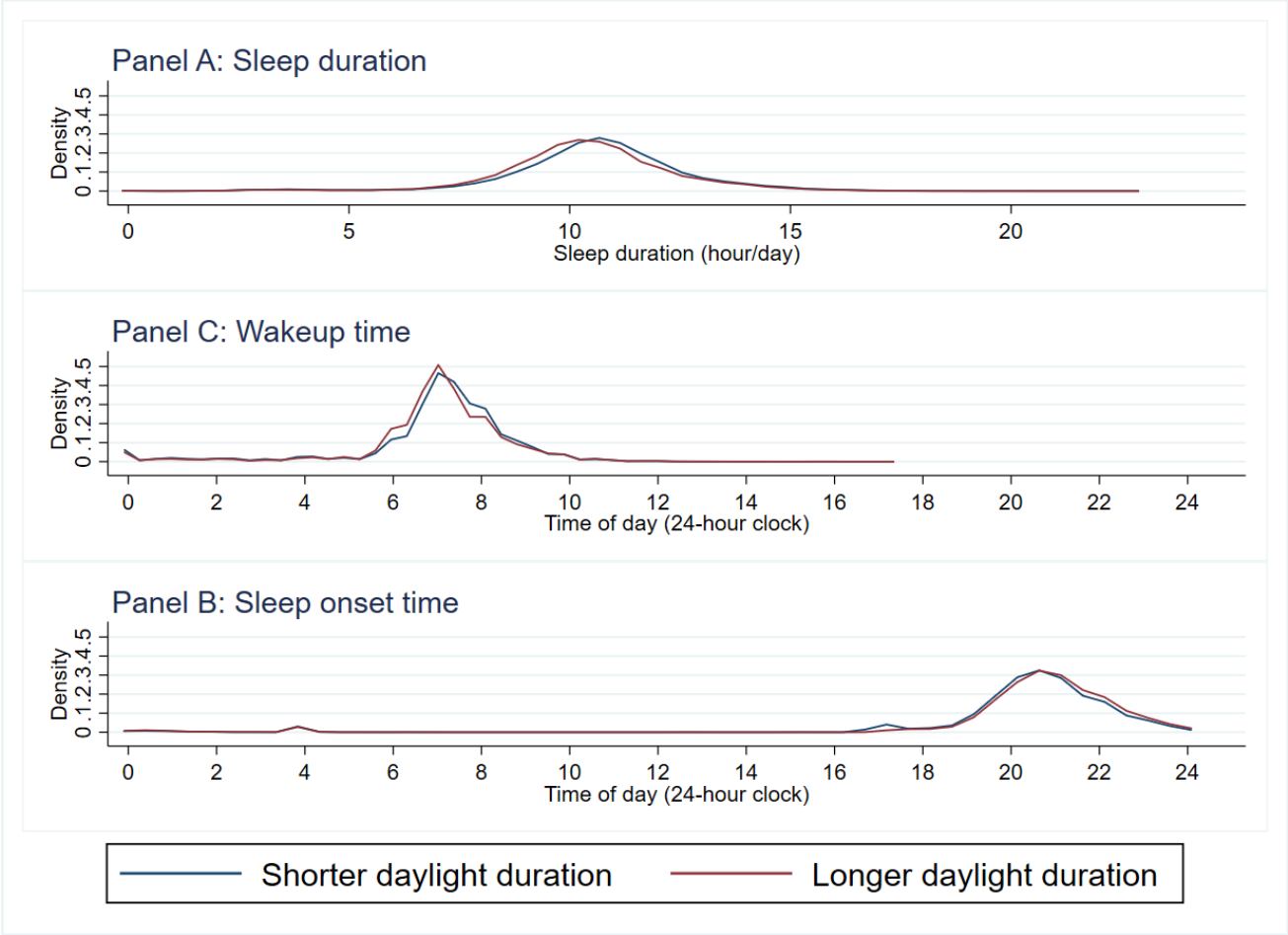
Notes: FE results are from the regression (1) while FE-IV results from models (1) and (2). F-statistic of IV denotes the F statistic for the excluded instrument in the first stage regression. Hausman test denotes p value from a Hausman test for endogeneity of the sleep duration variable in equation (2). Instrument: Daylight duration. Other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors clustered at the individual level are in parentheses. Results (coefficient estimates and standard errors) are multiplied by 100 for aesthetic purposes. The symbol *denotes significance at the 10% level, **at the 5% level, and ***at the 1% level

Appendix Figure A1: Distributions of sleep duration by weekdays/weekends



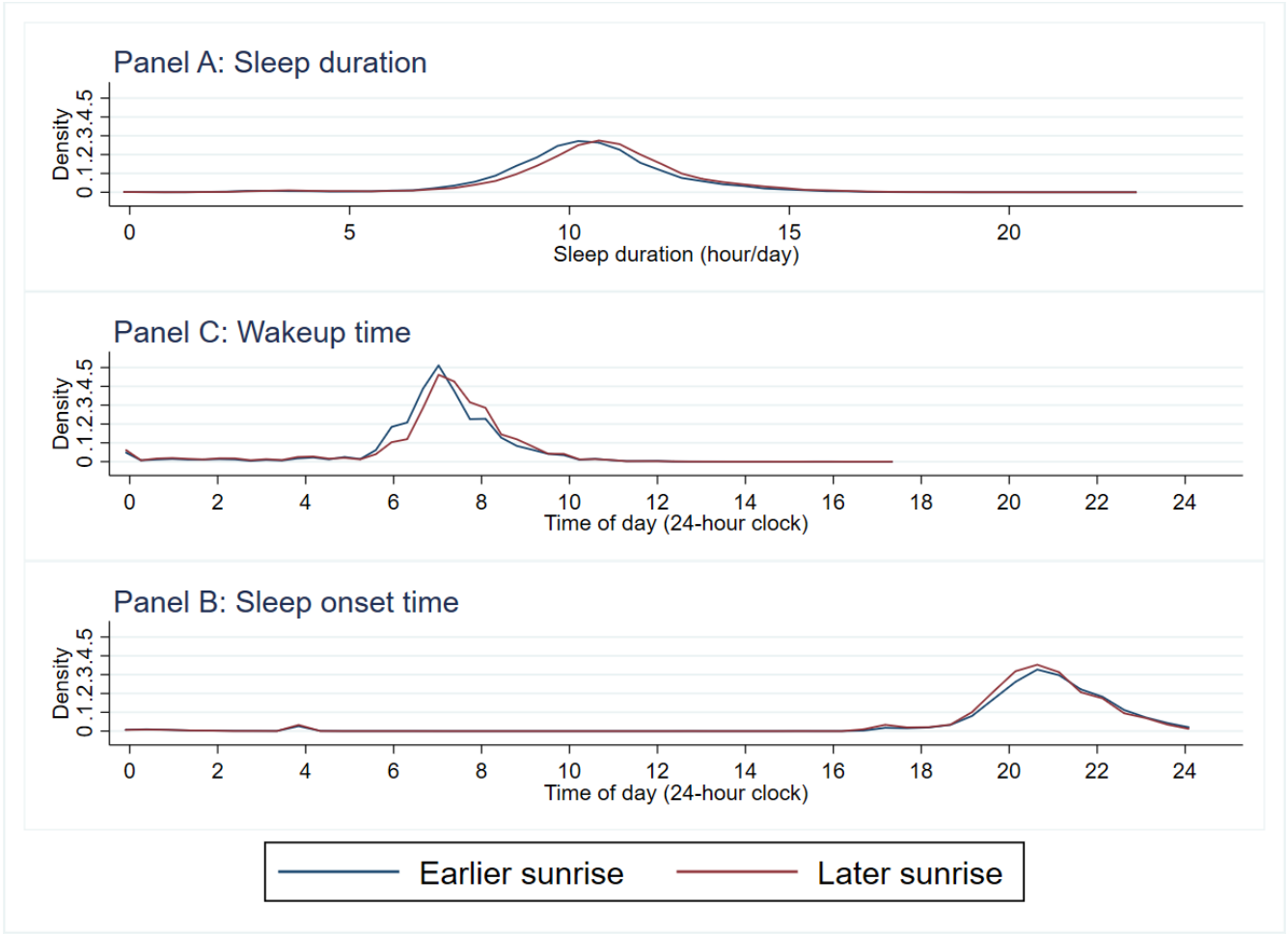
Notes: This figure reports sleep duration distribution for a pooled sample of all valid TUDs. Weekends include holidays.

Appendix Figure A2: Distributions of sleep duration, wakeup time and sleep onset time by daylight duration



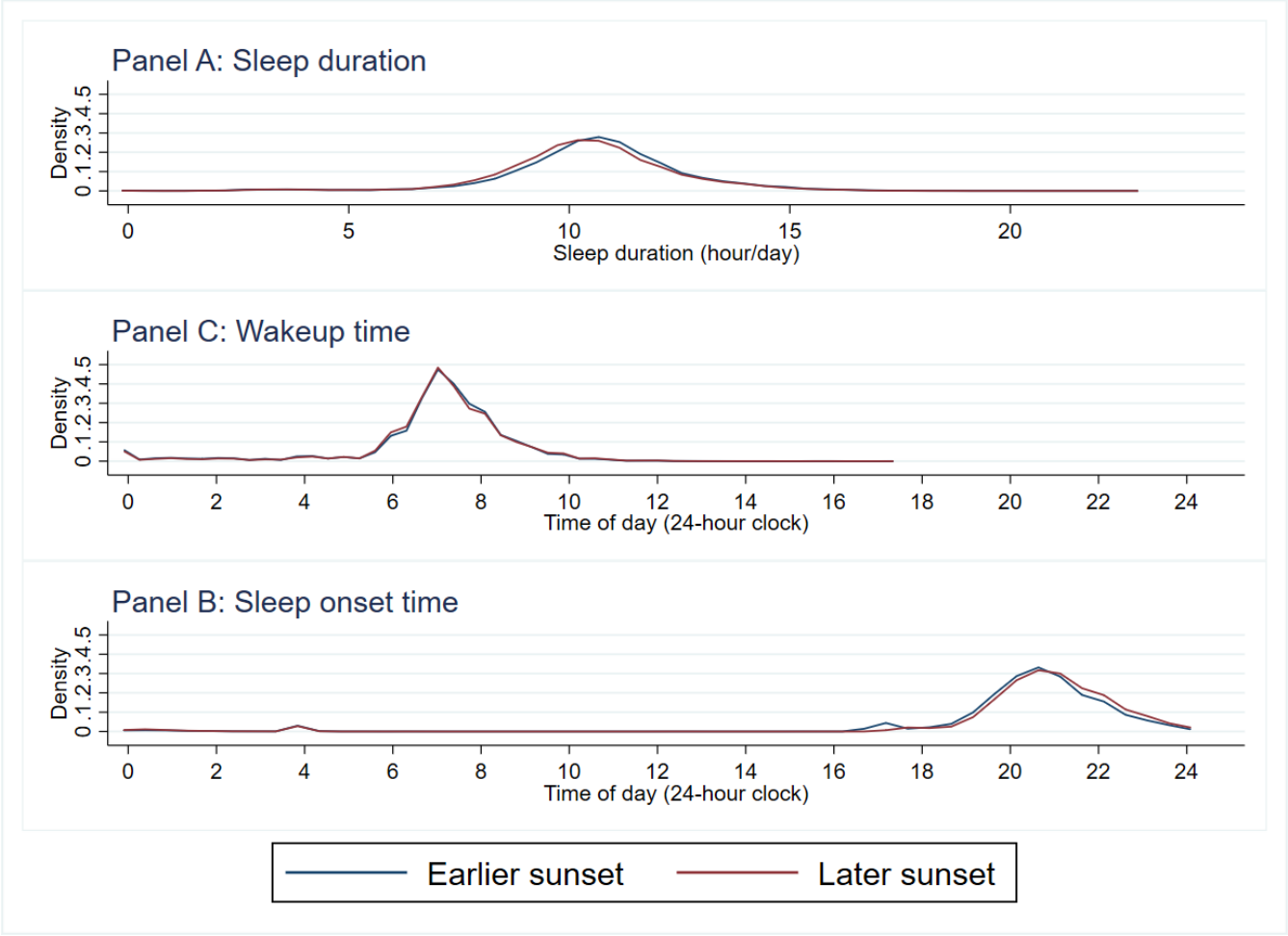
Notes: This figure reports univariate kernel density estimation of sleep duration (in hours per day), sleep onset time (in hour according to a 24-hour clock) and wakeup time (in hour according to a 24-hour clock) for a pooled sample of LSAC children with a valid TUD. "Longer daylight duration" indicates all TUDs recorded on dates with daylight duration at or above the median while "Shorter daylight duration" refers to those under the median.

Appendix Figure A3: Distributions of sleep duration, wakeup time and sleep onset time by sunrise time



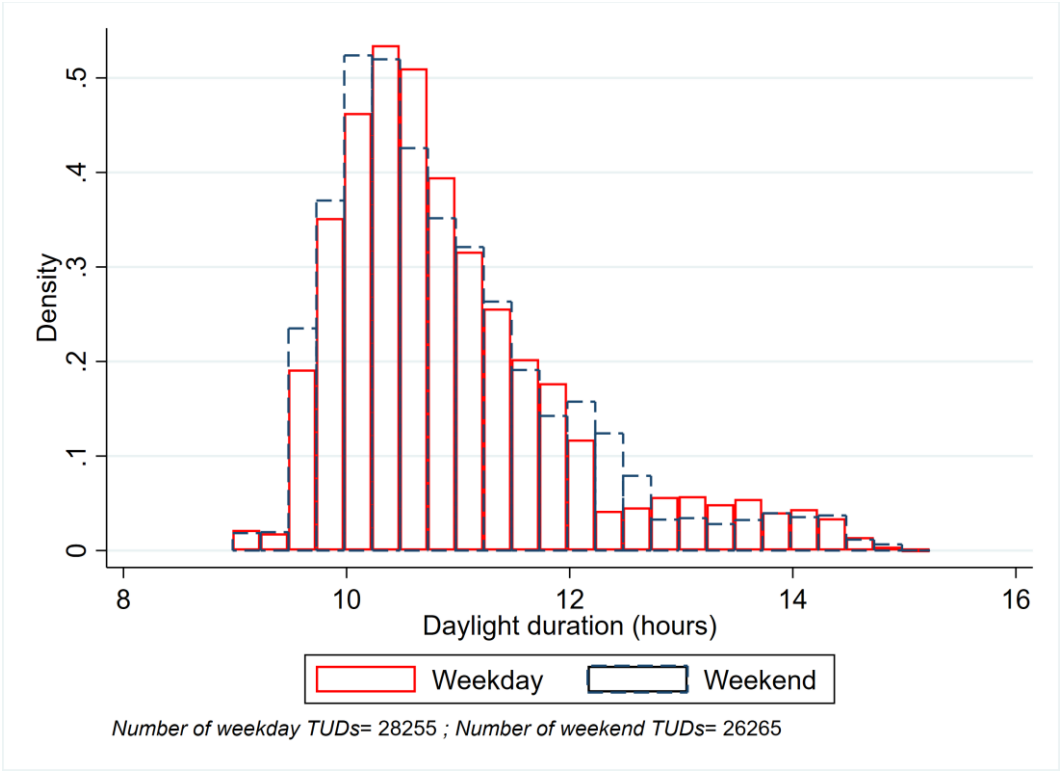
Notes: This figure reports univariate kernel density estimation of sleep duration (in hours per day), sleep onset time (in hour according to a 24-hour clock) and wakeup time (in hour according to a 24-hour clock) for a pooled sample of LSAC children with a valid TUD. "Earlier sunrise" indicates all TUDs recorded on dates with sunrise time at or above the median while "Later sunrise" refers to those under the median.

Appendix Figure A4: Distributions of sleep duration, wakeup time and sleep onset time by sunset time



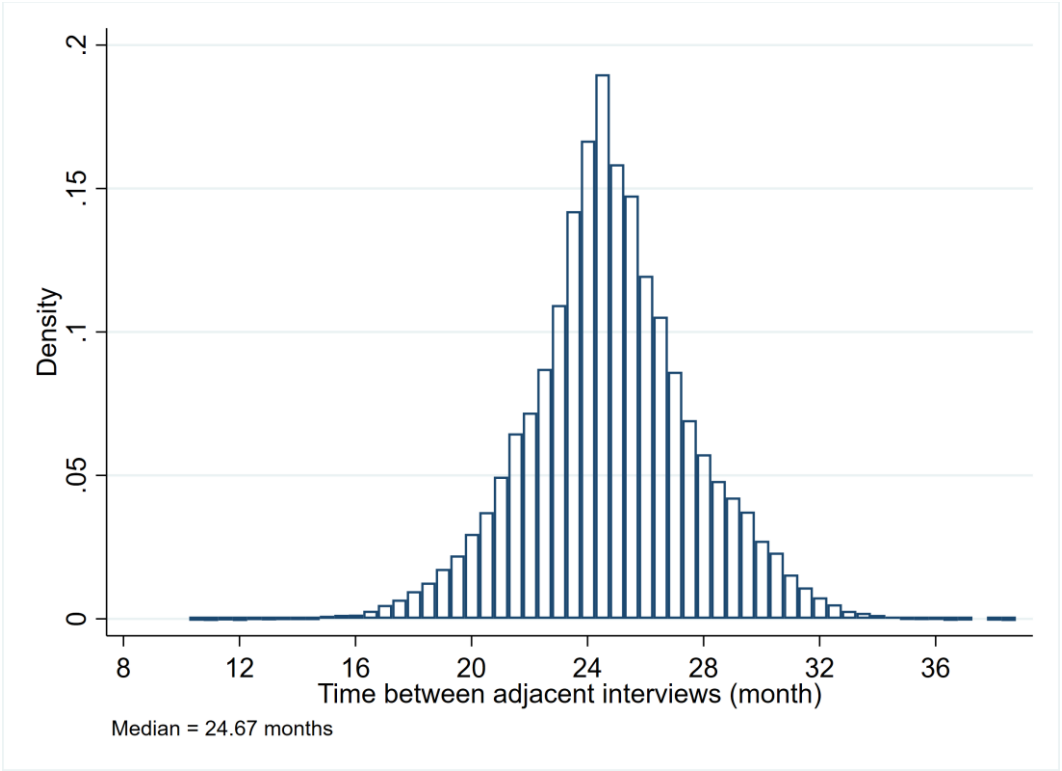
Notes: This figure reports univariate kernel density estimation of sleep duration (in hours per day), sleep onset time (in hour according to a 24-hour clock) and wakeup time (in hour according to a 24-hour clock) for a pooled sample of LSAC children with a valid TUD. "Earlier sunset" indicates all TUDs recorded on dates with sunset time at or above the median while "Later sunset" refers to those under the median.

Appendix Figure A5: Distributions of daylight duration recorded on TUD dates



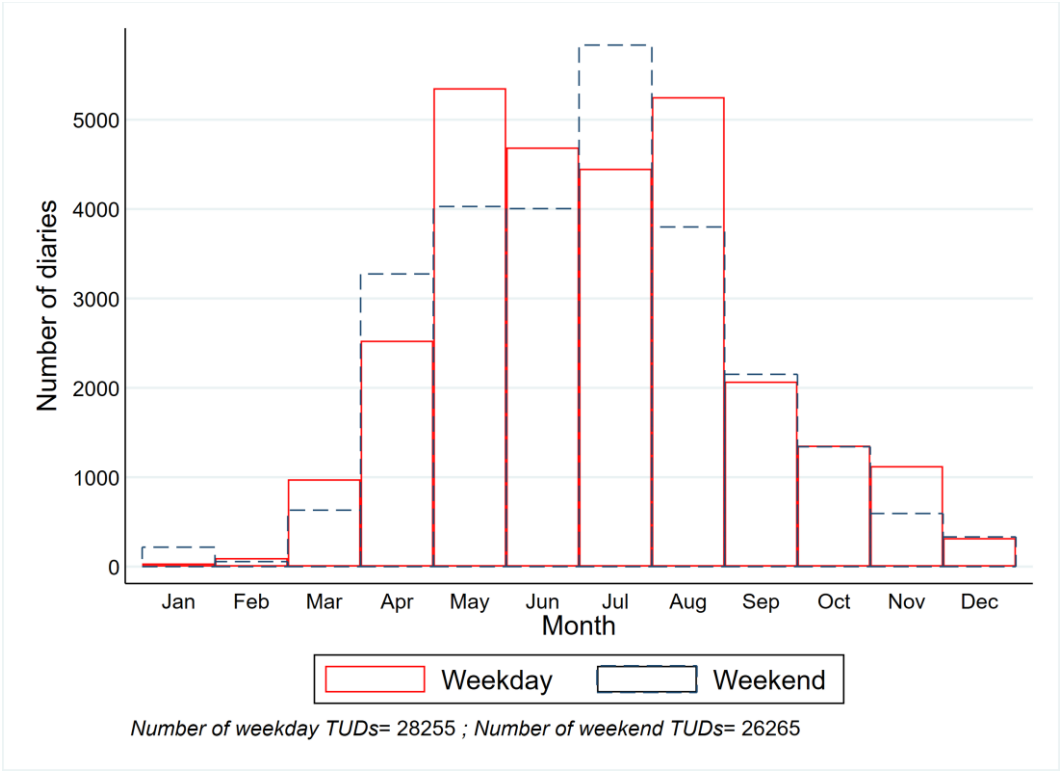
Notes: This figure reports daylight duration for a pooled sample of all valid TUDs. Weekends include holidays.

Appendix Figure A6: Distribution of time between adjacent interviews



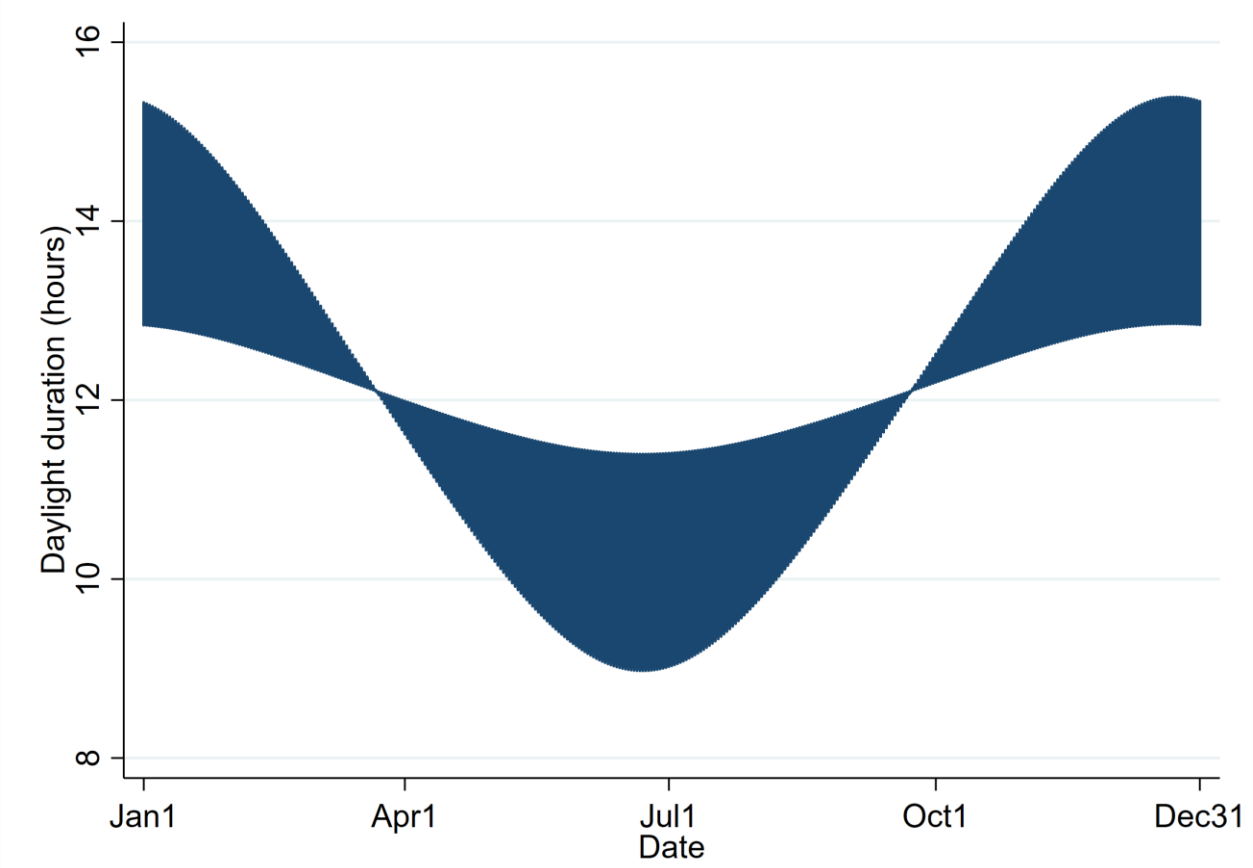
Notes: This figure reports distribution of time (in months) between two adjacent interviews for a pooled sample of all valid TUDs.

Appendix Figure A7: Distribution of time use diary months by weekdays/weekends



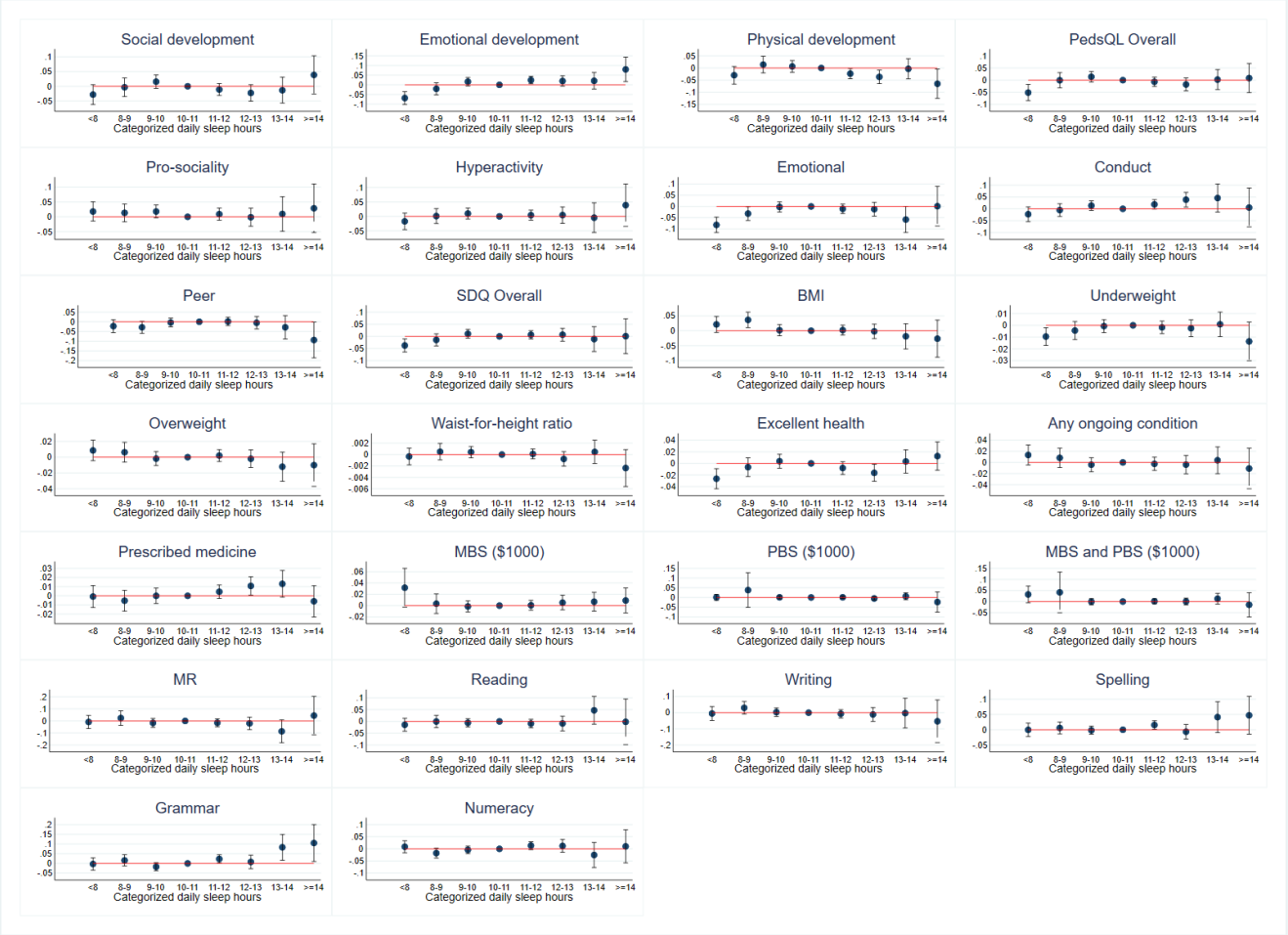
Notes: This figure reports the distribution of diary months for a pooled sample of all valid TUDs. Weekends include holidays.

Appendix Figure A8: Variations in daylight duration in LSAC TUDs



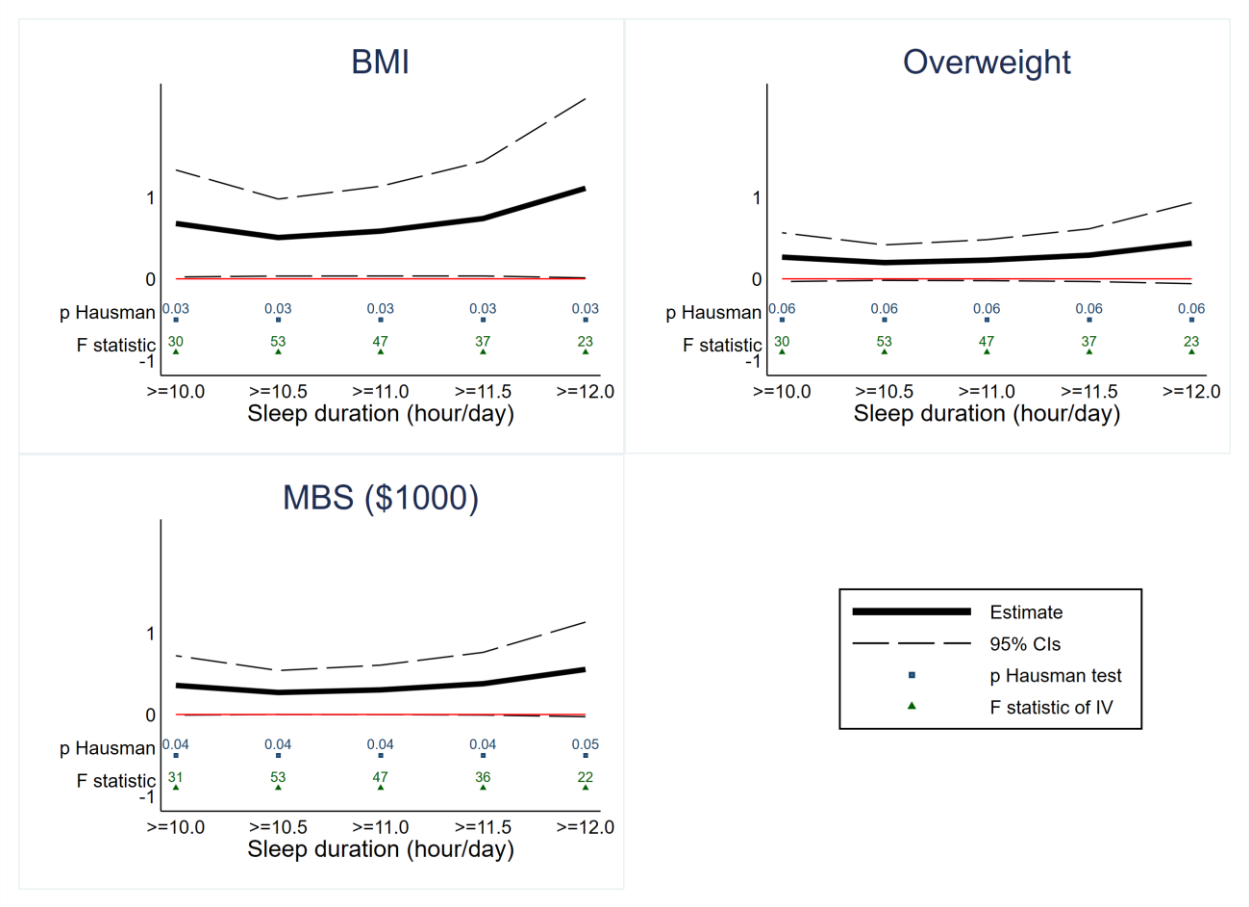
Notes: Each line in this figure shows daylight duration over a non-leap year for a postcode (among about 312 postcodes) sampled in LSAC TUDs.

Appendix Figure A9: Impact of sleep duration using categorized sleep hours



Notes: Results (in marginal effects) for each outcome are from a separate FE regression. Sleep duration is categorized with daily sleep duration between 10 and 11 hours is set as the base group. Other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors are clustered at the individual level.

Appendix Figure A10: Impact of sleep duration at different cut-offs



Notes: Results for each cut-off points are from a separate FE-IV regression. "F-statistic of IV" denotes the F statistic for the excluded instrument in the first stage regression. "P Hausman test" denotes p value from a Hausman test for endogeneity of the sleep duration cut-off variable in equation (2). Instrument: Daylight duration. Other explanatory variables include child age (and its square), maternal completed qualification, living with both parents, number of siblings; local socio-economic background variables, state/territory dummies, TUD year dummies, TUD quarter dummies, TUD day-of-week dummies, and a holiday indicator. Robust standard errors are clustered at the individual level

Appendix Table B1: Coding rules for activities by B cohort children

Grouping	Wave 1	Wave 2	Wave 3	Waves 6, 7 and 8
Sleep	Sleeping, napping	Sleeping, napping	Sleeping, napping	Sleeping/napping (not end of the day bed-time); Time between sleep (from response to the question "what time did you go to sleep?") and wake-up (next day, from response to the question "What time did you wake up?")
Personal care	Awake in bed / cot; Looking around, doing nothing; Bathe / nappy change, dress / hair care; Breastfeeding; Other eating, drinking, being fed; Crying, upset; Destroy things, create mess; Held, cuddled, comforted, soothed; Not sure what child was doing	Awake in bed; Eating, drinking, being fed; Bathing, dressing, hair care, health care; Doing nothing, bored/restless; Crying, upset, tantrum; Arguing, fighting; Destroy things, create mess; Being reprimanded; Being held, cuddled, comforted, soothed; Quiet free play; Not sure what child was doing;	Awake in bed; Eating, drinking, being fed; Bathing, dressing, hair care, health care; Doing nothing, bored/restless; Crying, upset, tantrum; Arguing, fighting; destroying things, creating mess; Being reprimanded; Being held, comforted, soothed; Quiet free play; Not sure what child was doing	Eating/drinking; Cleaning teeth; Showering/bathing; Getting dressed / getting ready; Personal care nec.; Doctor; Dentist/Orthodontist; Physiotherapist / Chiropractor; Medical/Health care; Personal care/Medical/Health Care nec.; Listening to music; Playing musical instruments or singing for leisure; Chess, card, paper and board games / crosswords; Games of chance / gambling; Hobbies, collections; Handwork crafts (excl. clothes making); Arts; Unstructured non-active play nec; Clubs; Religious groups; Doing nothing; Non-active activities nec.; Talking face-to-face; Talking on a landline phone; Non-verbal interaction; Negative face-to-face communication; Communication nec.; Illegal activities; Filling out the diary; Other; Uncodeable activity
School	Responses "Day care centre / playgroup" to the question "where was the child?"	Responses "Day care centre / playgroup" to the question "where was the child?"	Responses "Day care centre / playgroup" to the question "where was the child?"	School lessons, excluding Recess and Lunch

Grouping	Wave 1	Wave 2	Wave 3	Waves 6, 7 and 8
Education	Read a story, talked / sung to, sing / talk; Colour / draw, look at book, puzzles; Organised activities / playgroup	Read a story, told a story, sung to; Colour/draw, look at book, educational game; Organised lessons/activities	Read a story, talk/sing, talked/sung to; drawing/colouring, looking at book, etc.; organised lessons/activity	Private music lessons/practice, academic tutoring; Reading or being read to for leisure; Doing homework (not via electronic devices); Doing homework (electronic device); Attend courses (excluding school /university)
Physical	Crawl, climb, swing arms or legs; Other play, other activities; Visiting people, special event, party	Active free play; Visiting people, special event, party; Walking; Ride bicycle/trike	Active free play; visiting people, special event, outing; walking; travel in pusher/bicycle seat; ride bicycle, trike, etc.	Archery / Shooting sports; Athletics / Gymnastics; Fitness / Gym / Exercise; Ball Sports; Martial arts / Dancing; Motor Sports / Roller Sports / Cycling; Water/Ice/Snow Sports; Organised team sports and training other; Archery / Shooting sports (individual); Athletics / Gymnastics (individual); Fitness / Gym / Exercise (individual); Martial arts / Dancing (individual); Motor Sports / Roller Sports / Cycling (individual); Ball Sports (individual); Water/Ice/Snow Sports (individual); Organised individual sport and training other; Archery / Shooting sports (unstructured); Athletics / Gymnastics (unstructured); Fitness / Gym / Exercise (unstructured); Ball Sports (unstructured); Martial arts / Dancing (unstructured); Motor Sports / Roller Sports / Cycling (unstructured); Water/Ice/Snow Sports (unstructured); Unstructured active play Other; Walking pets/playing with pets; Active club activities; Shopping; Shopping; Purchasing consumer goods; Purchasing durable goods; Window shopping; Purchasing repair services; Purchasing administrative services; Purchasing personal care services; Purchasing other services; Attendance at movies / cinema; Attendance at concert/theatre; Attendance at museum / exhibition / art gallery; Attendance at zoo / animal park / botanic garden; Attendance at other mass events; Going out nec; Religious practice; Weddings, funerals, rites of passage; Religious activities / ritual ceremonies nec; Attending live sporting events; Active activities nec
Chores		Being taught to do chores	Being taught to do chores	Retailing; Hospitality (including fast food); Clerical/office; Labourers and related workers; Gardening / lawn mowing; Babysitting; Apprenticeships/trades persons; Working in a family business or farm; Work Other; Umpiring (work); Car washing (work); Animal care (work); Volunteering (work); Cleaning/tidying; Laundry/clothes care; Clothes making; Food/drink preparation; Food/drink clean up; Gardening (maintenance chores); Cleaning grounds/garage/shed/outside of house (chores); Pool care (chores); Animal care; Home maintenance; Design/Home Improvement; Heat/water/power upkeep; Car/boat/bike care; Selling/disposing of household assets; Rubbish/Recycling; Packing; Household management Other; Taking care of siblings (chores); Chores nec

Grouping	Wave 1	Wave 2	Wave 3	Waves 6, 7 and 8
Media	Watching TV, video or DVD; Listening to tapes, CD's, radio, music	Watching TV, video, DVD, movie; Listening to tapes, CDs, radio, music; Using computer, computer game	Watching TV, video, DVD, movie; listening to tapes, CDs, radio, music; using computer, computer game	Playing games (electronic device); Playing games (Electronic device) nfd; Watching TV programs or movies/videos; Spending time on social networking sites; Downloading/posting media; Internet shopping; General Internet browsing; Creating/maintaining websites; General application use; Electronic device use nec.; Talking on a mobile phone; Video chatting; Texting/emailing; Online chatting / Instant messaging
Travel	Taken places with adult (e.g. shopping); Taken out in pram or bicycle seat; Travel in car / other household vehicle; Travel on public transport, ferry, plane	Travel in car; Travel in a pusher/bicycle seat; Travel on public transport; Taken places with adult (e.g. Shopping)	Travel in car; travel on public transport; taken places with adult	Travel by foot; by bike, scooter, skateboard etc.; by private motor vehicle/bike; by public/chartered transport; Travel nec.

Appendix Table B2: Coding rules for activities by K cohort children

Grouping	Wave 1	Waves 2 and 3	Wave 4	Wave 5	Wave 6
Sleep	Sleeping, napping	Sleeping, napping	Sleeping/napping; Time between sleep (from response to the question "what time did you go to sleep?") and wake-up (next day, from response to the question "What time did you wake up?")	Sleeping/napping (not end of the day bed-time); Time between sleep (from response to the question "what time did you go to sleep?") and wake-up (next day, from response to the question "What time did you wake up?")	Sleeping/napping (not end of the day bed-time); Time between sleep (from response to the question "what time did you go to sleep?") and wake-up (next day, from response to the question "What time did you wake up?")
Personal care	Awake in bed; Eating and drinking; Bathe, dress, hair care, health care; Do nothing, bored/restless; Crying, upset, tantrum; Arguing, fighting, destroy things; Held, cuddled, comforted, soothed; Being reprimanded, corrected; Not sure what child was doing	Awake in bed; Eating and drinking; Bathe, dress, hair care, health care; Do nothing, bored/restless; Crying, upset, tantrum; Arguing, fighting, destroy things; Held, cuddled, comforted, soothed; Being reprimanded, corrected; Quiet free play; Not sure what child was doing	Eating/drinking; Bathing, dressing, toileting, teeth brushing, hair care; Dentist, Doctor, Chiropractor, Physio, Optometrist; Listening to music, CDs, playing music; Board or card games, puzzles, toys, art; Non-Active Club Activities i.e. Chess C; Doing nothing; Talking face to face; Other	Eating/drinking; Cleaning teeth; Showering/bathing; Getting dressed / getting ready; Personal care nec.; Doctor; Dentist; Physiotherapist / Chiropractor; Medical/Health care nec.; Listening to music, playing musical instruments or singing for leisure; Unstructured non-active play; Non-active club activities; Doing nothing; Non-active activities nec.; Talking face-to-face (in person not via electronic devices); Non-verbal interaction (e.g. cuddles); Negative face-to-face communication; Communication nec.; Filling out the diary; Other	Eating/drinking; Cleaning teeth; Showering/bathing; Getting dressed / getting ready; Personal care nec; Doctor; Dentist/Orthodontist; Physiotherapist / Chiropractor; Medical/Health care; Personal care/Medical/Health Care nec.; Listening to music; Playing musical instruments or singing for leisure; Chess, card, paper and board games / crosswords; Games of chance / gambling; Hobbies, collections; Handwork crafts (excl. clothes making); Arts; Unstructured non-active play nec; Clubs; Religious groups; Doing nothing; Non-active activities nec; Talking face-to-face; Talking on a landline phone; Non-verbal interaction; Negative face-to-face communication; Communication nec; Illegal activities; Filling out the diary; Other; Uncodeable activity
School	Responses "Day care centre / playgroup" to the question	Responses "School, after/; before school; care" to the	School Lessons, excluding Recess and Lunch	School Lessons, excluding Recess and Lunch	School Lessons, excluding Recess and Lunch

Grouping	Wave 1	Waves 2 and 3	Wave 4	Wave 5	Wave 6
	"where was the child?"	question "where was the child?"			
Education	Read a story, talk/sing, talked/sung to; colour, look at book, educational game; being taught to do chores, read, etc.; organised lessons / activities	Use computer/computer games (if this activity done for or as part of homework); Read a story, talk/sing, talked/sung to; Reading looking at book by self; Other organised lessons / activities	Private music, language, religion lessons, tutoring; Reading or being read to for leisure; Homework (not on computer) including music practice; Computer for homework - internet; Computer for homework - not internet	Private music lessons/practice, academic tutoring; Reading or being read to for leisure; Doing homework (not via electronic devices); Doing homework	Private music lessons/practice, academic tutoring; Reading or being read to for leisure; Doing homework (not via electronic devices); Doing homework (electronic device); Attend courses (excluding school /university)
Physical	Walk for travel or for fun; ride bicycle, trike etc. (travel or fun); other exercise - swim / dance/ run about; visiting people, special event, party; other play, other activities	Walk for travel or for fun; Ride bicycle, trike etc. (travel for fun); Visiting people, special event, party; Organised sport/physical activity; Other organised lessons / activities	Organised team sports and training i.e.; Organised individual sport i.e. swimming; Ball games, riding a bike, scooter, ska; Taking Pet for a walk; Scouts, girl guides, etc.; Shopping; Going out to museums, cultural events,; Cinema; Live Sporting Events	Organised team sports and training; Organised individual sport and training; Unstructured active play; Walking pets / playing with pets; Active club activities; Shopping; Going out to a concert, play, museum, art gallery, community or school event , an amusement park etc.; Religious activities / ritual ceremonies; Attending live sporting events; Active activities nec.	Archery / Shooting sports; Athletics / Gymnastics; Fitness / Gym / Exercise; Ball Sports; Martial arts / Dancing; Motor Sports / Roller Sports / Cycling; Water/Ice/Snow Sports; Organised team sports and training other; Archery / Shooting sports (individual); Athletics / Gymnastics (individual); Fitness / Gym / Exercise (individual); Martial arts / Dancing (individual); Motor Sports / Roller Sports / Cycling (individual); Ball Sports (individual); Water/Ice/Snow Sports (individual); Organised individual sport and training other; Archery / Shooting sports (unstructured); Athletics / Gymnastics (unstructured); Fitness / Gym / Exercise (unstructured); Ball Sports (unstructured); Martial arts / Dancing (unstructured); Motor Sports / Roller

Grouping	Wave 1	Waves 2 and 3	Wave 4	Wave 5	Wave 6
					Sports / Cycling (unstructured); Water/Ice/Snow Sports (unstructured); Unstructured active play Other; Walking pets/playing with pets; Active club activities; Shopping; Shopping; Purchasing consumer goods; Purchasing durable goods; Window shopping; Purchasing repair services; Purchasing administrative services; Purchasing personal care services; Purchasing other services; Attendance at movies / cinema; Attendance at concert/theatre; Attendance at museum / exhibition / art gallery; Attendance at zoo / animal park / botanic garden; Attendance at other mass events; Going out nec; Religious practice; Weddings, funerals, rites of passage; Religious activities / ritual ceremonies nec; Attending live sporting events; Active activities nec.
Chores		Helping with chores/jobs	Making own bed, tidying own room; Making, preparing own food; Getting self ready, packing own school; Cleaning, tidying other rooms; Cooking, meal preparation, making lunch; Washing dishes, stacking and emptying d; Gardening, putting out the bin; Taking care of siblings, other children; Taking care of pets (excluding Walking pets)	Retailing (including fast food); Pamphlet delivering; Umpiring/refereeing; Car washing; Gardening / lawn mowing; Babysitting; Animal care; Working in a family business or farm; Work nec.; Volunteering; Cleaning/tidying; Laundry/clothes care; Food/drink preparation; Food/drink clean up; Gardening / lawn mowing; Animal care (excluding active play); Home maintenance; Taking care of siblings; Chores nec	Retailing; Hospitality (including fast food); Clerical/office; Labourers and related workers; Gardening / lawn mowing; Babysitting; Apprenticeships/trades persons; Working in a family business or farm; Work Other; Umpiring (work); Car washing (work); Animal care (work); Volunteering (work); Cleaning/tidying; Laundry/clothes care; Clothes making; Food/drink preparation; Food/drink clean up; Gardening (maintenance chores); Cleaning grounds/garage/shed/outside of house (chores); Pool care (chores); Animal care; Home maintenance; Design/Home Improvement; Heat/water/power upkeep; Car/boat/bike care; Selling/disposing of household assets; Rubbish/Recycling; Packing; Household

Grouping	Wave 1	Waves 2 and 3	Wave 4	Wave 5	Wave 6
					management Other; Taking care of siblings (chores); Chores nec
Media	Watching TV, video, DVD, movie; Listening to tapes, CD's, radio, music; Use computer/computer games	Watching TV, video, DVD, movie; Listening to tapes, CD's, radio, music; Use computer/computer games (if this activity done NOT for or NOT as part of homework)	Electronic media, games, computer use; Computer games - internet; Computer games - not internet; Xbox, Playstation, Nintendo, WII etc.; Internet not covered elsewhere; TV/DVD; Talking on a landline phone; Talking on a mobile phone; Texting, email, social networking - facebook/twitter; Skype or Webcam	Playing games; Watching TV programs or movies/videos; Spending time on social networking sites; Downloading/posting media (e.g. music, videos, applications); Internet shopping (excluding downloading/posting media); General Internet browsing (excluding homework); Creating/maintaining websites (excluding social networking profile); General application use (e.g. Microsoft Office; excluding homework); Electronic device use nec.; Talking on a landline phone (not video chat); Talking on a mobile phone (not video chat); Video chatting (e.g. Skype); Texting/emailing; Online chatting / Instant messaging	Playing games (electronic device); Playing games (Electronic device) nfd.; Watching TV programs or movies/videos; Spending time on social networking sites; Downloading/posting media; Internet shopping; General Internet browsing; Creating/maintaining websites; General application use; Electronic device use nec; Talking on a mobile phone; Video chatting; Texting/emailing; Online chatting / Instant messaging
Travel	Travel in pusher or on bicycle seat; travel in car / other household vehicle; travel on public transport, ferry, plane; taken places with	Travel in car; Travel on public transport; Taken places with adult (e.g. Shopping)	Travel by foot; by bike, scooter, skateboard etc.; by private car; Travel by public transport such as bus	Travel by foot; by bike, scooter, skateboard etc.; by private motor vehicle/bike; by public/chartered transport such as bus, taxi or aeroplane; Travel nec.	Travel by foot; by bike, scooter, skateboard etc.; by private motor vehicle/bike; by public/chartered transport; Travel nec.

Grouping	Wave 1	Waves 2 and 3	Wave 4	Wave 5	Wave 6
	adult (e.g. shopping)				

Appendix C: Robustness checks for the estimated relationship between daylight duration and children's time allocation

Appendix Table A5 presents results from several robustness checks for the estimated relationship between daylight duration and children's time allocation. Panel A reports the estimates of daylight duration from a pooled regression model where we do not control for individual fixed effects. In this pooled regression, we follow previous studies (Gibson & Shrader 2018; Jagnani 2022) to additionally control for postcode fixed effects so identification of the daylight duration impact on time allocation comes from daily variation in daylight duration across different individuals within a given postcode. We find that, with some exceptions where pooled estimates of daylight duration are slightly more pronounced in terms of the statistical significance or magnitude than the baseline FE estimates, our results change little. The similarity between pooled and FE estimates suggests that, in the absence of panel data as in the case for all prior studies, it would be suitable to use a pooled regression model to examine the relationship between daily solar cycles and sleep duration.

We next follow Jagnani (2022) to exclude all child and household level variables from the baseline FE regression model. The results, reported in Panel B of Appendix Table A5, show little sensitivity in the estimates of daylight duration on all time allocation variables. Finally, we experiment with including weather conditions[28] recorded on the TUD date as additional explanatory variables in the original FE regression model. The results, reported in Panel C of Appendix Table A5, indicate that, with an exception that daily maximum temperatures may affect sleep duration (marginally statistically significant at 10% level), none of included weather variables statistically significantly explains sleep duration, sleep onset time or wakeup time. Moreover, including weather conditions, while not changing the estimate of daily daylight duration on sleep duration in any significant way, does render the estimate of daylight duration on sleep onset time to become statistically insignificant. We also note that additionally controlling for weather conditions decreases the magnitude and statistical level of estimates of daylight duration on some non-sleep variables such as personal care or physical activity. Lastly, consistent with prior evidence (Nguyen et al. 2021a; Nguyen et al. 2021b), our results show that, on days with unfavourable weather

[28] Historical weather data from all monitoring stations in Australia were obtained from the Australian Bureau of Meteorology. As have been done previously (Nguyen et al. 2021a; Nguyen et al. 2021b), we assign daily weather elements from the three spatially closest weather stations to the individual's residential postcode centroid. Furthermore, we consider two weather elements which have been shown to affect children's time allocation: daily maximum temperature (and its square) and precipitation.

conditions, as represented by cold or hot temperatures or rain, individuals spend statistically significantly less time on physical activities, mainly by allocating more time to media activities.