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Cross-national differences in adolescents' sleep patterns: a time-use approach

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ABSTRACT

Good sleep contributes to health and performance. However, insufficient and poor sleep are very common among adolescents today. This study examines cross-national differences in adolescents' sleep and activity patterns across Finland, France, Hungary, Italy, Netherlands, South Africa, South Korea, Spain, and the UK, using an innovative 24-hour time-use approach with time-diary data ($N = 25{,}248$ diaries; mean age 15.4 years; 50.3% girls). Sleep duration ranges from 7:21 hours (South Korea) to 8:46 hours (South Africa, UK) on schooldays and from 9:13 hours (South Korea) to 10:33 hours (Netherlands) on non-schooldays. South Africa shows the earliest and Spain the latest sleep onsets and wake-up-times. Insufficient sleep duration (i.e. less than 8 hours) ranges from 19% (South Africa) to 69% (South Korea) on schooldays. Activity patterns before sleep (e.g. eating, screen time, studying) also differ strongly across countries. Our findings could support policy makers in developing effective strategies to improve adolescent sleep.

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Adolescence; sleep; time use; time-diary data; cross-national comparisons

Introduction

Adolescents' insufficient and poor sleep is a major public health concern across the globe (Chattu et al., 2018). Although the American Academic of Pediatrics recommends that adolescents sleep at least 8 to 10 hours (Paruthi et al., 2016), millions of adolescents are not achieving this goal, especially on schooldays (Gradisar et al., 2011; Matricciani et al., 2012; Patte et al., 2017). Previous research has found that insufficient sleep (*i.e.*, less than 8 hours per day of sleep) is associated with adolescent' increased physical and mental health problems, poorer school performance, as well as more absenteeism, learning problems, bad mood, and car accidents (Chaput et al., 2016; Garaulet et al., 2011; Henderson et al., 2019, Hyseni Duraku et al., 2015; Master et al., 2023; Raniti et al., 2017; Shochat et al., 2014; Short & Weber, 2018; Short et al., 2013; Vaca et al., 2005). Examining adolescents' sleep and the factors leading to insufficient sleep is therefore of crucial importance to understand individuals' well-being and health outcomes.

The problem of adolescents' insufficient sleep is explained by a combination of biological and psychosocial/environmental factors. All these factors lead to a delay of sleep times during adolescence, which clashes with early school hours and results in wide-spread insufficient sleep (Crowley et al., 2018). During adolescence, for instance, there are substantial changes in the biological processes regulating sleep. In particular, the biological clock (regulating 24-hour rhythms such the

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sleep wake-cycle) pushes adolescent sleep times later. At the same time, sleep pressure builds-up slower, which keeps adolescents awake in the evening and further contributes to later sleep times (Carskadon, 2011; Crowley et al., 2014; Jenni et al., 2005). Environmental factors have an impact on adolescent sleep too. For example, family contexts can influence adolescents' exposure to blue-light-emitting devices during evening hours (an additional factor leading to later sleep times), due to differences in parenting styles and family routines that regulate adolescents' activity patterns (e.g. Gracia & García-Román, 2018). Other examples of environmental factors include school policies, such as governments' regulation of school hours. Depending on when and for how long schools open, adolescents will have to adapt to such hours, which in turn impacts their sleep duration and timing (Chang et al., 2015; Kubiszewski et al., 2014; Pyper et al., 2017; Wheaton et al., 2016). Consequently, if countries differ significantly in terms of school policies (e.g. regulation of school hours), adolescents' daily practices (e.g. leisure styles) and cultural beliefs and norms towards adolescent sleep practices (e.g. shared bedroom with siblings vs. sleeping alone) (Gracia et al., 2020; Owens, 2004), adolescent sleep patterns may vary across countries with different policy and sociocultural contexts.

In this study, we examine cross-national variations in adolescents' sleep duration and sleep timing, including sleep onset (*i.e.*, start of the sleep period) and wake-up time (*i.e.*, end of the sleep period). Only a few studies have performed direct cross-national comparisons of adolescents' sleep patterns (Gariepy et al., 2020; Kuula et al., 2019; Ong et al., 2019), while there are also some meta-analyses and reviews that have compared sleep patterns across countries (Buckhalt & Suh, 2014; Gradisar et al., 2011; Matricciani et al., 2012; Olds et al., 2010). A picture that emerges from summarizing the main findings of the cited reviews and meta-analyses is that adolescents living in Asian countries sleep the shortest followed by North American adolescents, while adolescents living in Europe and Oceania usually sleep the longest. Findings from European studies are less clear. Some studies found shorter sleep durations in Southern regions, whereas others found that adolescent sleep duration is shorter in Northern or Eastern regions (Gariepy et al., 2020; Kuula et al., 2019). While the cross-national literature on adolescent sleep has made relevant contributions, there are various limitations that need to be addressed. First, studies have used different methodological approaches, ranging from actigraphy (only a few studies, e.g. Ong et al., 2019) to sleep diaries, questionnaires and surveys (see Gradisar et al., 2011; Olds et al., 2010 for an overview of sleep assessments methods used). Consequently, new studies using cohesive methodologies with a comparable cross-national design are needed. Second, previous studies have often used surveys that do not allow to distinguish between time spent in bed (awake and asleep) and time spent asleep, resulting in 'an under-representation of sleep problems as it does not consider sleep onset latency (i.e. lying awake in bed before falling asleep)' (Vandendriessche et al., 2021, p. 830). Third, previous studies have used stylized questions that ask adolescents to provide their approximate bedtimes and wake-up times using half-hourly intervals, from which sleep patterns are then calculated (see Gariepy et al., 2020, for example). Previous studies have demonstrated that stylized measures are subject to higher measurement error than data obtained from time diaries, where respondents report their exact activities for every 10 minutes throughout a full day (24 hours) (Gracia et al., 2020; Hertog & Zhou, 2021; Kan & Pudney, 2008). These limitations in the adolescent sleep literature call for further cross-national research in this field of research.

Our study tackles the mentioned limitations in previous cross-national literature on adolescent sleep patterns by adopting a novel 24-hour-time-use approach based on time-diary data. Time-diary methods are regarded as the gold standard of population-level methodologies for analysing the duration and timing of individuals' daily activities (e.g. sleep patterns) by means of studying 10-minutes activity slots over the day (Bauman et al., 2019). Our approach allows to provide a highly precise analysis of the duration and timing of adolescent sleep by accurately differentiating between bedtime before falling asleep (i.e. using a smartphone in bed) and actual reported sleep (i.e. time reported as sleep). Our 24-hour time-diary method also enables to examine how adolescents participate in activities that happen closely before sleep onset that may hamper adolescent sleep quality, including screen time, physical activity, homework, and late dinners. While some studies

have compared adolescent daily activity patterns cross-nationally (e.g. sedentary and eating behaviour, social media use, schoolwork pressure) (Cosma et al., 2020; Craig et al., 2020; Inchley, 2017), there is a lack of cross-national studies focusing on evening activities done before going to bed, which can have a great impact on sleep. For example, the use of blue-light emitting devices before sleep time (e.g. smartphones, laptops, screen monitors) is known to negatively impact sleep (Ricketts et al., 2022), but how these behaviours vary across national contexts with different policy, cultural and economic characteristics is still unclear. Our study tackles these knowledge gap in the literature. The aim of this study was to compare sleep and activity patterns across nine countries to identify macro-level societal determinants of adolescents' insufficient sleep. The study addresses two main questions, namely (1) how adolescent sleep patterns (i.e. sleep duration, sleep onset, and wake-up time) differ across countries, day type (schoolday vs. non-schoolday) gender and age, and (2) how activity patterns prior to sleep time differ across national contexts. The nine national cases included in our study capture cross-cultural and cross-policy regional variations, including six countries from Western Europe (i.e. Finland, France, Italy, the Netherlands, Spain, and the UK), but also one country from Eastern Europe (i.e. Hungary), one country from Sub-Saharan Africa (i.e. South Africa) and an East Asian case (i.e. South Korea).

Data and methodology

Data and sample

This study uses largescale population-based cross-national time-diary data from the Multinational Time Use Study (MTUS). The MTUS is a collection of time diary surveys that have been harmonized for comparability across time and space (Fisher et al., 2019). Time diary data is considered the most reliable and precise source to study the use of time of the population (Sevilla, 2014). Time use surveys are characterized by the collection of information by means of a 24-hours diary, in which respondents report their specific activities and where they engaged in such activities every 10 minutes. Sociodemographic information about respondents, their household and other co-resident persons are also collected. Our final sample is composed by adolescents (age range: 12–19 years) from nine countries. Details on sample characteristics and distributions are included in the Table 1.

Table 1. Sample description.

Country	Abbrev.	Year	n diaries	N	Mean Age	% Boys	% Girls	% Schooldays	% Non-Schooldays
Spain	ES	2009	1	1479	15.6	51.3	48.7	41.9	58.1
Finland	FI	2009	2	879	15.5	48.0	52.0	38.3	61.7
France	FR	2009	2	1008	15.6	45.7	54.3	35.8	64.2
Hungary	HU	2009	1	657	15.8	50.4	49.6	50.5	49.5
Italy	IT	2008	1	3326	15.6	50.6	49.4	42.7	57.3
South Korea	KR	2009	2	5840	15.1	51.0	49.0	69.1	30.9
Netherlands	NL	2005	7	2772	15.4	47.5	52.5	70.9	29.1
United Kingdom	UK	2014	2	1734	15.5	46.3	53.7	38.7	61.3
South Africa	ZA	2010	1	7553	15.6	50.1	49.9	50.4	49.6
Total				25248	15.4	49.7	50.3	53.7	46.3

Source: Own Calculations from the Multinational Time Use Study (MTUS) (Fisher et al., 2019).

For most countries data have been collected all year-round, except for South Korea (September), the Netherlands (October) and South Africa (October-December). We have run sensitivity analyses, that are available upon request, and reveal that the main findings of the study are stable and not affected by the period of data collection. MTUS provides weights for the samples, and they are representative of the total population of each country. Sleep patterns are estimated from the diary that corresponds to one day of data collection (for

some countries more than one day of data per respondents is available; this has been considered in the statistical analyses). Our data come from fully anonymized secondary data (Multinational Time Use Study) collected in the context of different studies, which have been approved by the respective local ethics committees and conducted in accordance with the Declaration of Helsinki on human subjects testing.

Outcome measures

We study five measures of adolescent sleep that are taken directly from the time diaries filled by respondents. The respondents are asked to report the type of activity they did across a 24-hour day with a frequency of 10 minutes. For each 24-hour time-diary a total of 144 entries (6 per hour) are analysed. We consider 'sleep' when the main activity reported in the diary was coded as *2 'Sleep and naps' or 3 'Imputed sleep'*. From these entries the following sleep variables were calculated : (1) *Sleep duration*: Number of minutes during which respondents report being asleep between sleep onset and wake up time; (2) *Insufficient sleep*: Proportion of respondents whose sleep duration was less than the recommended 8 hours per day; we use this threshold as the minimum average sleep requirement recommended by institutions like the American Academic of Pediatrics (Paruthi et al., 2016); (3) *Timing of sleep*: Proportion of respondents who report 'sleep' as a main activity at any moment of the day. This measure includes sleep timing during other moments of the day and not only at night, as for example naps; (4) *Sleep onset*: The first entry in the diary in which respondents report 'sleep' after 8pm; (5) *Wake-up time*: The first entry in the diary in which respondents report a non-sleep activity after a period of sleep.

We additionally study another relevant outcome measure, namely *activity patterns prior to sleep onset*, a measure that captures the distribution of activity patterns among adolescents during the two hours before sleep onset. This window of time allows for enough observations and span (a total of twelve 10-minutes activity slots) to capture trends in adolescents' pre-sleep activity patterns, including eating, working, studying, doing unpaid work, travelling, physical activity, screen-based activities, indoor leisure, socializing, other types of leisure, personal care, and other activities. The rationale behind studying adolescents' time use before their sleep onset is motivated by previous studies indicating that time spent doing certain activities during evening hours can influence sleep onset and sleep duration (Chang et al., 2015; Munezawa et al., 2011; Van den Bulck, 2004).

Empirical strategy

We start by briefly reporting cross-national variations in adolescent sleep through unadjusted descriptive analyses. We subsequently apply multivariate statistical models with ID as random factor to investigate the effect of country (9 levels), day type (schoolday vs. schoolday; schooldays are defined as days in which students reported attending school for school-related activities), gender (boys vs. girls) and age (continuous measure) as fixed factors. We use gender and age as additional predictors in our analyses guided by previous research from various countries revealing that gender and age are relevant predictors of individuals' sleep patterns (García-Román et al., 2022; Gariepy et al., 2020; Roenneberg et al., 2004). We conduct the multivariate statistical analyses for a pooled sample of all countries with country-level covariates (these results are reported in Table 3); and also separately by country to study how age, gender, and type of day are associated with adolescent sleep in each country, using standard linear models (without random effects) for countries with only one diary per respondent in the data, and linear mixed models (with respondent ID as random effect) for countries with more than one diary observation (these results are reported in Table 4). Finally, we describe adolescents' activity patterns before sleep onset by reporting the distribution of adolescents' activity patterns for each 10-minute interval during the last two hours before sleep onset (i.e. from 120 to 10 minutes before sleep onset) on both schooldays and non-schooldays.

Results

Main analyses - adolescent sleep patterns

In the following paragraphs we describe the effects of country, type of day, gender and age on sleep patterns. Table 2 presents the (unadjusted) averages for sleep duration, sleep onset and wake-up time on schooldays and non-schooldays by country. Measures for sleep duration reveal that adolescents sleep longer on non-schooldays compared to schooldays in all countries. The difference between schooldays and non-schooldays is around 100 minutes, with the largest difference of 125 minutes in South Korea and the smallest of 79 minutes in South Africa. On schooldays, South Korean adolescents sleep on average 7 hours and 21 minutes. This is 40 and 47 minutes less than Spanish and Italian adolescents, the next in the ranking. South African and British adolescents sleep the longest on schooldays with 8 hours and 46 minutes, followed by the Dutch (8 hours and 38 minutes). On non-schooldays, South Korea is again the country with the shortest sleep duration (9 hours and 13 minutes), followed by Spain and Italy (9 hours and 44 minutes and 9 hours and 50 minutes, respectively). The longest sleep duration on non-schooldays is observed in the Netherlands (10 hours and 33 minutes), followed by France (10 hours and 25 minutes) and Hungary (10 hours and 15 minutes). Table 2 also shows that South Africa is the country with the earliest sleep onsets and wake-up-times, whereas Spain is the country of all nine with the latest sleep onsets and wake-up-times. The (unadjusted) patterns of sleep onsets and wake-up-times are presented graphically in Figure 1.

Table 2. Averages of the sleep parameters on schooldays and non-schooldays by country.

	Total sleep duration (in minutes)		Insufficient sleep (% of respondents sleeping less than 8 hours)		Sleep onset		Wake-up time	
Country	Schoolday	Non-Schoolday	Schoolday	Non-Schoolday	Schoolday	Non-Schoolday	Schoolday	Non-Schoolday
Spain	481	584	42.5	17.7	23:31	0:32	7:33	10:16
Finland	506	597	30.1	15.4	22:49	23:32	7:15	9:29
France	514	625	30.2	9.6	22:25	23:13	6:58	9:38
Hungary	500	615	32.3	10.8	21:57	22:26	6:16	8:41
Italy	488	590	35.9	11.5	22:52	23:33	7:00	9:23
South Korea	441	553	68.9	21.0	23:39	23:32	7:00	8:44
Netherlands	518	633	26.1	8.4	22:47	23:05	7:25	9:38
UK	526	608	22.4	13.4	22:34	23:13	7:20	9:21
South Africa	526	594	19.4	9.6	21:19	21:26	6:05	7:20

Source: Own Calculations from the Multinational Time Use Study (MTUS) (Fisher et al., 2019).

To test statistically the effect of country on sleep patterns, Spain was used as reference category, given that Spanish adolescents report the latest sleep onsets and wake-up times, and among the shortest sleep durations. Overall, Spanish adolescents sleep significantly shorter compared to adolescents from the other countries (Dutch adolescents sleep 40.3 minutes longer, $p < 0.001$; French 37.4 minutes longer, $p < 0.001$; UK 31.8 minutes longer, $p < 0.001$; South African 29.3 minutes longer, $p < 0.001$; Hungarian 25.9 minutes longer, $p < 0.001$; Finnish 19.3 minutes longer, $p < 0.01$; Table 3). The only exceptions are South Korean adolescents who sleep 39.2 minutes shorter ($p < 0.001$), and Italian adolescents whose sleep duration does not significantly differ from their Spanish counterparts ($p > 0.05$).

As for sleep duration, adolescents from all countries show statistically significantly earlier sleep onset times, compared to Spain, with the largest difference observed in South Africa (sleep onset 164.5 minutes earlier, $p < 0.001$), followed by Hungary (116.3 minutes earlier, $p < 0.001$), and France, the Netherlands and UK (respectively 75.5, 70.1 and 69.6 minutes earlier, $p < 0.001$; Table 3 and Figure 1). Regarding wake-up time, we observe similar patterns as for sleep onset. Adolescents from all countries wake up significantly earlier than their Spanish counterparts, again with South African adolescents exhibiting the most substantial difference

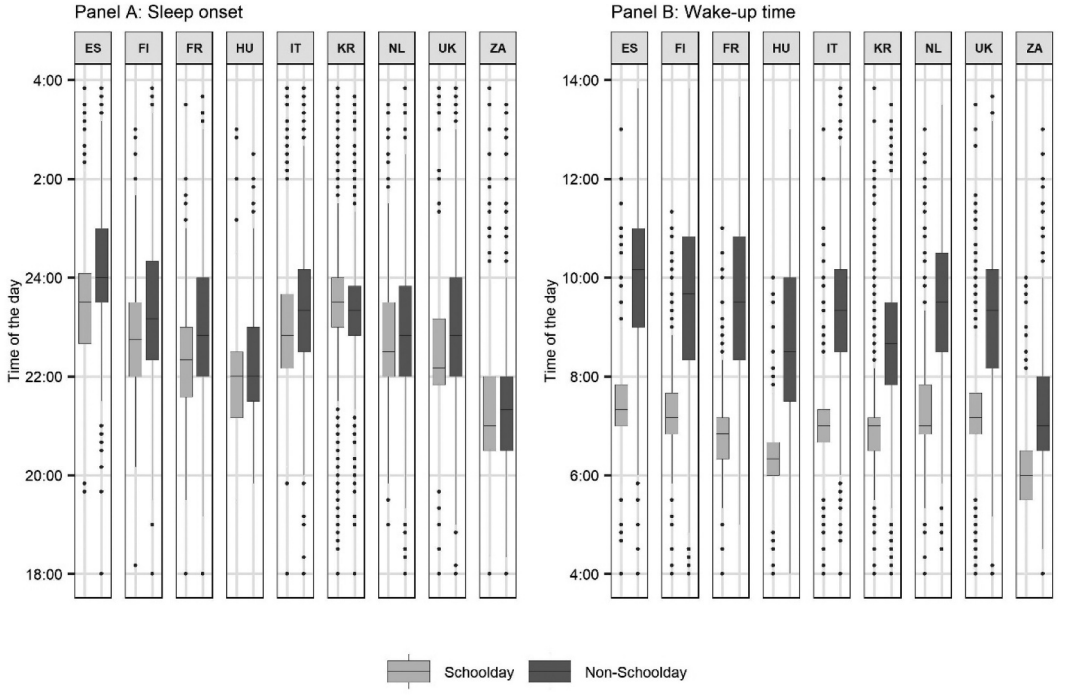

Figure 1. Distribution of sleep onset (panel A) and wake-up time (panel B) by country and type of day. Source: Own Calculations from the Multinational Time Use Study (MTUS) (Fisher et al., 2019). Boxplots represent the interquartile range (IRQ) with the horizontal line indicating the median sleep onsets (Panel A) and wake-up times (Panel B) separately for schooldays and non-schooldays and by country. The more stretched the box plots are, the greater the heterogeneity within countries is. The whiskers represent the lowest and highest values still within the 1.5 IQR of the lower and upper quartiles. Dots correspond to individuals who report data outside of the whiskers. The country abbreviations are as follows: NL (the Netherlands), UK (United Kingdom), ZA (South Africa), FI (Finland), FR (France), HU (Hungary), IT (Italy), ES (Spain), KR (South Korea).

Table 3. Linear mixed models with ID as random effect for sleep duration, sleep duration and wake-up time.

Variable	Category	Sleep duration	Sleep onset	Wake up time
Age		−9,1 ***	9,9 ***	1,2 ***
		(0,37)	(0.37)	(0.33)
Type of day	Schoolday	−104,8 ***	−12,0 ***	−117,3 ***
(ref=Non-Schoolday)		(1,22)	(1.08)	(1.07)
Gender	Girl	−5,0 **	−4,7 **	−8,8 ***
(ref=Boy)		(1,72)	(1.72)	(1.51)
Country	Finland	19,3 **	−52,4 ***	−32,7 ***
(ref=Spain)		(6,25)	(6.5)	(5.48)
	France	37,4 ***	−75,5 ***	−38,0 ***
		(5,95)	(6.19)	(5.22)
	Hungary	25,9 ***	−116,3 ***	−90,2 ***
		(5,73)	(5.85)	(5.02)
	Italy	4,6	−48,4 ***	−44,2 ***
		(3,83)	(3.92)	(3.36)
	South Korea	−39,2 ***	−25,8 ***	−64,2 ***
		(3,81)	(3.93)	(3.34)
	Netherlands	40,3 ***	−70,1 ***	−29,3 ***
		(6,29)	(6.64)	(5.52)
	UK	31,8 ***	−69,6 ***	−37,5 ***
		(4,98)	(5.17)	(4.37)
	South Africa	29,3 ***	−164,5 ***	−134,8 ***
		(3,46)	(3.55)	(3.04)
(Intercept)		733,8 ***	1065,9 ***	351,6 ***
		(7,13)	(7.08)	(6.25)

For each outcome variable (sleep duration, sleep onset, wake-up time) the estimates (b coefficient), standard errors in brackets and p-values are reported. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

Sleep time and sleep onset estimate the minute of the day when the event takes place. Values are between 1 (4am) and 1440 (3:50am).

(134.8 minutes earlier, $p < 0.001$), followed by Hungarian (90.2 minutes earlier, $p < 0.001$), and South Korean adolescents (64.2 minutes earlier, $p < 0.001$; Table 3 and Figure 1). The country-dependent variations in sleep patterns are additionally depicted in Figure 2. Here the proportion of adolescents asleep at each moment of the day (not only at night) is shown. These additional analyses reveal that a proportion of Spanish adolescents sleeps during early afternoon on both schooldays and non-schooldays (with around 6% of Spanish adolescents reporting sleep at 4pm).

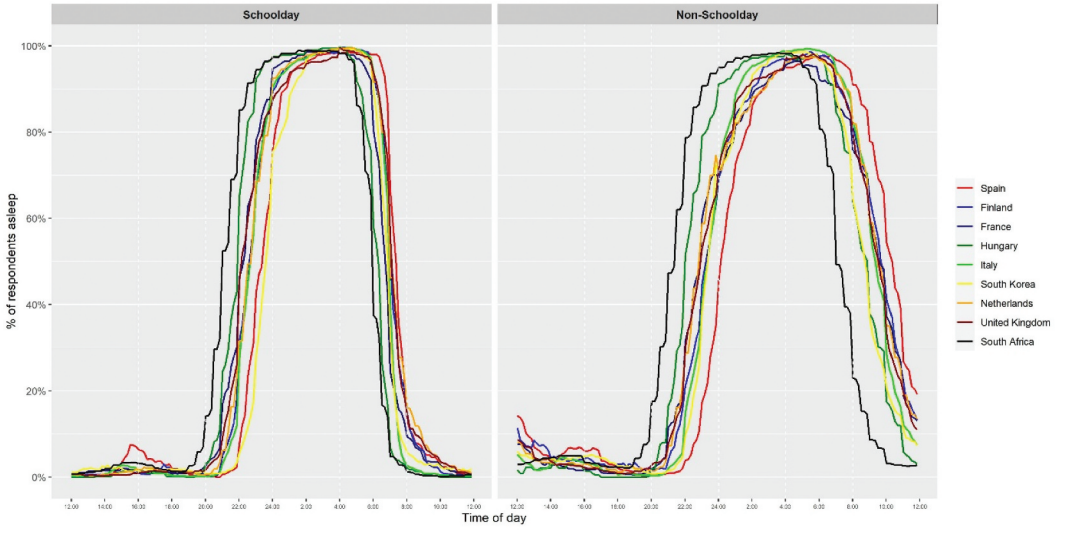

Figure 2. Proportion of respondents asleep by type of day. Source: Own Calculations from the Multinational Time Use Study (MTUS) (Fisher et al., 2019). Analyses show the percentage of respondents asleep in each country for every 10-minute slot activity between during the 24 hours of the day.

When considering type of day, sleep patterns are very different between schooldays and non-schooldays. Sleep duration is shorter on schooldays (104.8 minutes, $p < 0.001$, Table 3) compared to non-schooldays. This effect is consistent across countries (analyses done separately for each country show that in all countries adolescents sleep significantly shorter on schooldays, Table 4). The proportion of adolescents with insufficient sleep duration (i.e. less than 8 hours per day) varies from 19% in South Africa to 69% in South Korea on schooldays and is reduced by about a third on non-schooldays across the different countries (Figure 3). Sleep onset is earlier on schooldays compared to non-schooldays (12 minutes, $p < 0.001$), when looking at the pooled sample (Table 3 and Figure 1). However, when analysing the nine countries separately, we observe a few exceptions. While for most of the countries sleep onset is earlier on schooldays, South African adolescents do not change their sleep onset depending on the type of day ($p > 0.05$), and South Korean adolescents sleep later on schooldays (but only 7.5 minutes later, $p < 0.001$, Table 4). Wake-up time, like sleep duration, shows a clear pattern across countries with significantly earlier wake-up times in all countries on schooldays compared to non-schooldays (117.3 minutes, $p < 0.001$, Table 3 and Figure 1).

Regarding age differences in adolescent sleep, we found clear variations for all three measures of sleep: sleep duration, sleep onset, and wake-up time. In the analyses with the pooled sample (Table 3), we observe that older adolescents sleep shorter (9 minutes less for each additional year, $p < 0.001$), sleep later (10 minutes later for each year older, $p < 0.001$) and wake up later (1.2 minutes later for each year older, $p < 0.001$) compared to younger adolescents. When we look at the effect of age separately by country (Table 4), we observe significant associations between age and sleep duration as well as sleep onset for all countries ($p < 0.001$). Regarding wake-up time, we observe similar results across countries (later wake-up times for older adolescents; Table 3), but differences

Table 4. Linear (mixed) models for sleep duration, sleep onset and wake-up time by country.

			Linear models				Linear mixed models With Respondent ID as Random effect				
			Spain	Hungary	Italy	South Africa	Finland	France	South Korea	Netherlands	UK
Sleep duration	Age		−12.6 ***	−10 ***	−10.4 ***	−7.5 ***	−9.6 ***	−7.9 ***	−7.3 ***	−6.7 ***	−9.1 ***
			(1.2)	(1.6)	(0.7)	(0.5)	(2.6)	(2)	(0.6)	(1.3)	(1.5)
	Type of day (ref=Non-Schoolday)	Schoolday	−107 ***	−115.5 ***	−105.9 ***	−73.9 ***	−100.8 ***	−122.3 ***	−112.6 ***	−115.3 ***	−87.9 ***
			(5.6)	(7.9)	(3.2)	(2.2)	(7.3)	(6.5)	(2.4)	(3.7)	(5.7)
	Gender (ref=Boy)	Girl	−18.5 ***	6.1	−1	−2.3	−14.6	−4.2	−7.3 *	−4.2	−11.6
			(5.6)	(7.9)	(3.1)	(2.2)	(11)	(9.3)	(2.8)	(5.9)	(6.7)
	(Intercept)		810 ***	764 ***	755.1 ***	717.1 ***	773.6 ***	759.2 ***	676.2 ***	743.9 ***	768 ***
			(21.3)	(29.6)	(12.3)	(8.5)	(42.5)	(34.7)	(10.9)	(22.2)	(25.3)
Sleep onset	Age		15.4 ***	10.7 ***	11.4 ***	8 ***	12.7 ***	14.3 ***	11.8 ***	14.9 ***	15.7 ***
			(1)	(1.2)	(0.6)	(0.4)	(2.1)	(2.5)	(0.6)	(1.6)	(1.3)
	Type of day (ref=Non-Schoolday)	Schoolday	−55.7 ***	−28.4 ***	−36.1 ***	−0.5	−27.4 ***	−43.7 ***	7.5 ***	−19.6 ***	−30.6 ***
			(4.5)	(5.9)	(2.5)	(2)	(4.8)	(7.4)	(2.1)	(3.8)	(4.3)
	Gender (ref=Boy)	Girl	4.2	−2.9	−5.7 *	−5 *	12.5	−1	0.6	0.6	−6.7
			(4.5)	(5.9)	(2.5)	(2)	(9)	(11.7)	(2.6)	(7.3)	(5.7)
	(Intercept)		983.8 ***	941.2 ***	1002 ***	926.7 ***	952 ***	929.9 ***	989.9 ***	916.6 ***	917.4 ***
			(17.1)	(22.1)	(9.8)	(7.8)	(34.8)	(43.5)	(9.9)	(27.6)	(21.6)
Wake up	Age		2.8 **	0.7	1.1	0.5	3	6.4 **	4.5 ***	8.1 ***	6.5 ***
			(1)	(1.3)	(0.5)	(0.4)	(2)	(2)	(0.5)	(1.3)	(1.2)
	Type of day (ref=Non-Schoolday)	Schoolday	−162.7 ***	−143.9 ***	−142 ***	−74.4 ***	−132 ***	−167.5 ***	−104.9 ***	−134.7 ***	−120.5 ***
			(4.6)	(6.3)	(2.5)	(1.8)	(6.2)	(6.5)	(2)	(3.6)	(4.5)
	Gender (ref=Boy)	Girl	−14.3 **	3.3	−6.7 **	−7.3 ***	−2.3	−5.2	−6.8 **	−3.6	−18.3 ***
			(4.5)	(6.3)	(2.4)	(1.7)	(8.7)	(9.6)	(2.4)	(5.6)	(5.3)
	(Intercept)		353.8 ***	265.2 ***	316.8 ***	203.8 ***	288 ***	250.1 ***	226.2 ***	220.4 ***	248.2 ***
			(17.4)	(23.4)	(9.6)	(6.9)	(33.6)	(35.6)	(9.2)	(21.5)	(20)

For each outcome variable (sleep duration, sleep onset, wake-up time) the estimates (b coefficient), standard errors in brackets and p-values are reported. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.
Sleep time and sleep onset estimate the minute of the day when the event take place. Values are between 1 and 1440 with 1 representing 4am.
Linear models are for countries with only one observation by respondent, and linear mixed models for countries with more than one observation by respondent.

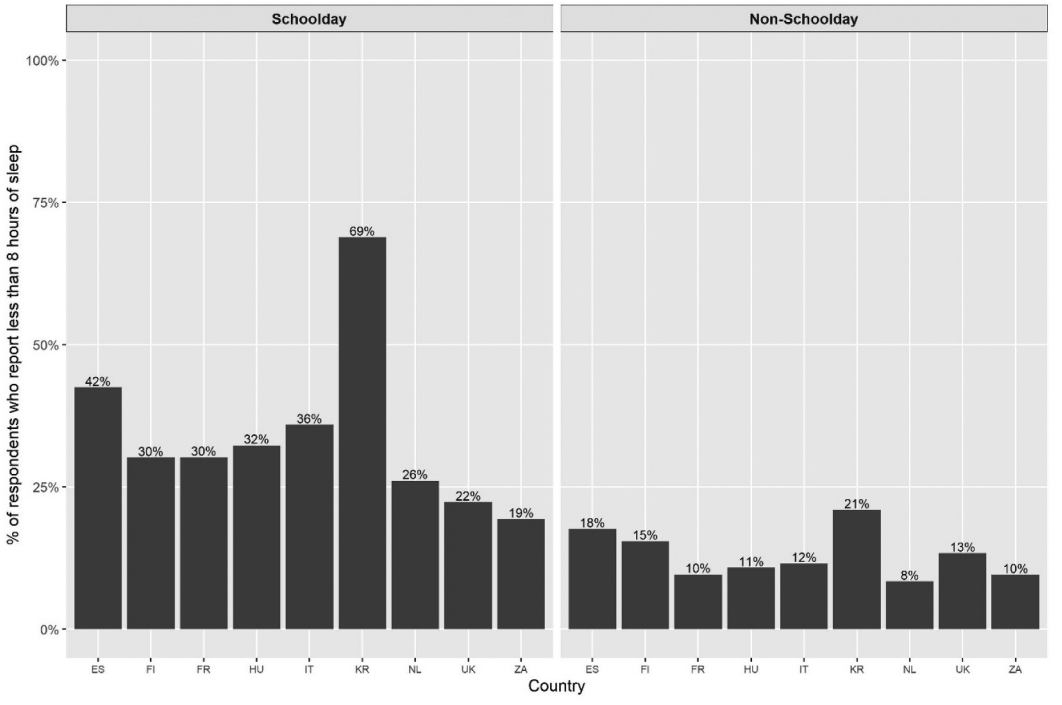

Figure 3. Insufficient sleep (measured as less than 8 hours of sleep per day) by type of day and country. Source: Own Calculations from the Multinational Time Use Study (MTUS) (Fisher et al., 2019). The country abbreviations are as follows: NL (the Netherlands), UK (United Kingdom), ZA (South Africa), FI (Finland), FR (France), HU (Hungary), IT (Italy), ES (Spain), KR (South Korea).

are only statistically significant for South Korea, Netherlands, the UK ($p < 0.001$), France and Spain ($p < 0.01$).

As for gender, we also found significant differences in adolescent sleep patterns. For the combined pooled sample (Table 3), we observe that girls sleep 5 minutes less ($p < 0.01$), go to bed 5 minutes earlier ($p < 0.01$) and wake up 9 minutes earlier ($p < 0.001$) than boys. The separate analyses by country show similar patterns across countries, but also interesting country variations (Table 4). While boys tend to sleep longer than girls across countries, differences in sleep duration between boys and girls are only statistically significant in Spain (18 minutes, $p < 0.001$) and South Korea (7 minutes, $p < 0.05$). There are no statistically significant differences in sleep onset (except for Italy and South Africa where girls sleep 6 minutes earlier, $p < 0.05$), whereas girls wake up earlier than boys in all countries (except for Hungary) and this difference is statistically significant for Spain, Italy, and South Korea ($p < 0.01$), South Africa and UK ($p < 0.001$).

Additional analyses – daily activity patterns prior to sleep onset

Figure 4 shows the proportion of adolescents engaging in each activity for every 10-minutes interval during the last two hours prior to sleep onset. We observe strong country differences in adolescents' activity patterns prior to sleep onset at four key levels. First, Mediterranean countries (Spain, France, and Italy) are characterized by the highest proportion of respondents having meals closely before sleep onset, and such percentage increases markedly as sleep onset time approaches, especially during schooldays. For example, in Italy more than 25% of adolescents report eating in the last interval before sleep onset on schooldays.

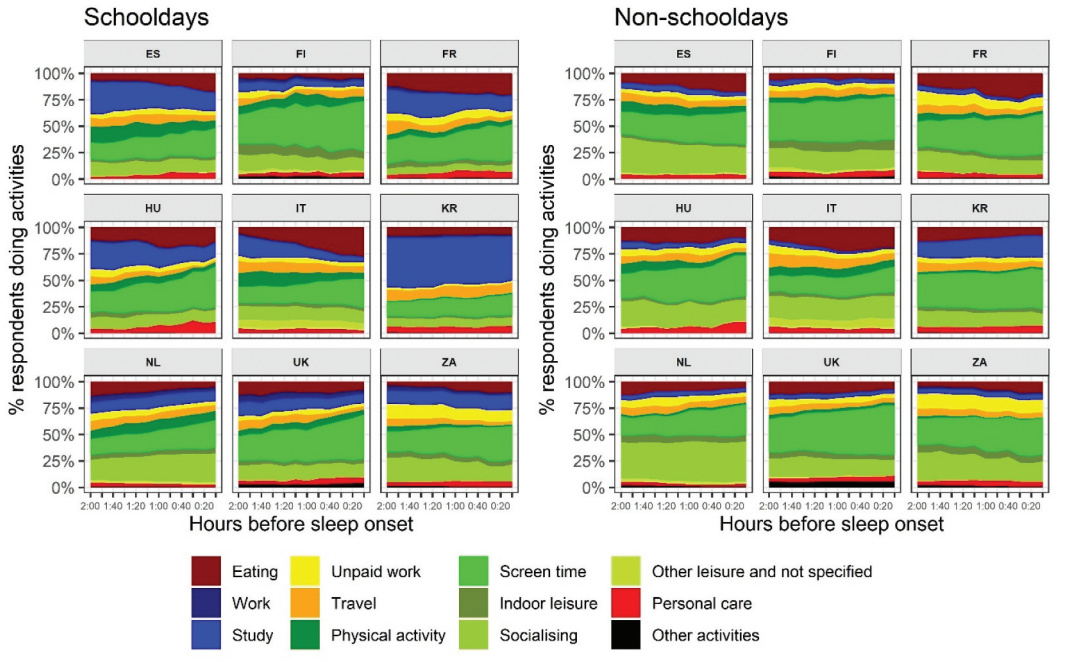

Figure 4. Tempo-graphs of activities carried out 2 hours before sleep onset for schooldays and non-schooldays. Source: Own Calculations from the Multinational Time Use Study (MTUS) (Fisher et al., 2019). Activities in the graphs are in the same order as in the legend. The country abbreviations are as follows: NL (the Netherlands), UK (United Kingdom), ZA (South Africa), FI (Finland), FR (France), HU (Hungary), IT (Italy), ES (Spain), KR (South Korea).

Second, we observe a group of countries where screen-based time is most salient, particularly United Kingdom and Finland. This pattern is remarkable on both schooldays and non-schooldays. In the United Kingdom, almost 50% of adolescents spend time doing screen-based activities just before sleep onset (last 10 minutes before sleep onset), with similar results for Finland. Hungary, just like France, shows a large incidence of adolescents' screen-time use right before sleep onset (about 40%), while Hungarian adolescents spend less time than French eating and focus more on personal care.

Third, the Netherlands shows the highest percentage of adolescents who report socializing prior to sleep onset (about 25% on schooldays and about 35% on non-schooldays). Socializing is more commonly done on non-schooldays in all countries.

Fourth, and finally, we observe that South Korea presents the highest proportion of adolescents studying before sleep onset. Studying is more common on schooldays than non-schooldays in all countries. For the concrete case of South Korea, more than 40% of South Korean adolescents are studying during the entire 2-hours period before sleep onset, while in the other countries this proportion does not exceed 25%, except for Spain but only at the beginning of the two-hour period considered. During non-schooldays the proportion of adolescents who report studying is about 20% in South Korea, while in the other countries barely exceeds 5%.

Discussion

This study has analysed adolescents' sleep patterns in nine countries, covering six cases from Western Europe (i.e. Finland, France, Italy, Netherlands, Spain, and the UK), one from Eastern Europe (i.e. Hungary), one from Sub-Saharan Africa (i.e. South Africa) and one from East Asia (i.e. South Korea). We document cross-country differences in adolescent sleep at the international level

by bringing a novel 24-hour time-diary approach that adds to existing literature by offering an accurate measurement of adolescents' sleep duration, sleep onset and wake-up time, as well as by showing how the exact nature of adolescents' activity patterns right before their sleep onset time differs across countries with different policy, cultural and economic characteristics.

The findings from our study reveal substantial cross-national variations in adolescents' sleep patterns. We find that South Korea has the shortest sleep duration by far with a worrying 69% of adolescents not sleeping enough (less than 8 hours) on schooldays, and that adolescents from South Korea also go to sleep late. This finding adds to earlier analyses on the extremely short sleep duration of adolescents in (East) Asia, including a recent time-use study on adolescents in the Japanese context (Buckhalt & Suh, 2014; Gradisar et al., 2011; Hertog & Zhou, 2021; Olds et al., 2010; Ong et al., 2019). Additionally, Spanish adolescents present the latest sleep onset and wake-up times, consistent with the late dinner, social activity patterns, and parental working hours of this national context (Gracia & García-Román, 2018). Meanwhile, South Africa shows sleep patterns that are more consistent with health recommendations, with very long sleep durations and the earliest sleep times and lowest incidence of insufficient sleep of all nine countries. These healthy sleep patterns in South Africa are closely followed by some Western European countries, including the Netherlands and the United Kingdom. Still, even in these countries, around 20% of adolescents do not get enough sleep (less than 8 hours) on schooldays, and across countries (especially in Spain) we also observe napping behaviour, implying that insufficient sleep remains a serious health problem among young people.

Our findings are also unique in that we examine the exact activities carried out by adolescents during the two hours before their sleep onset, an important indicator in the context of adolescent sleep quality across countries. Adolescents show an important incidence of screen-based time within the hour before starting to sleep, a practice associated with poorer sleep quality (Chang et al., 2015; Munezawa et al., 2011; Ricketts et al., 2022) that is particularly prevalent in the UK and Finland. While evening screen time has been found to be detrimental for the quality of sleep (Cain & Gradisar, 2010), eating before sleep time and engaging in homework can also contribute to lower sleep quality (Chung et al., 2020; Haan, 2020). We document a widespread presence of late meal habits in the Mediterranean countries (e.g. Italy, Spain), which reflects the distinctive structure of young people's activity patterns in Southern Europe (Gracia & García-Román, 2018; Gracia et al., 2020). Studying prior to sleep onset was a distinct frequent pattern of South Korean teenagers. Unfortunately, we only have data from one East Asian country, which limits our interpretation of the finding within the context of this region. Still, our finding showing high prevalence of doing homework and studying prior to sleep onset in South Korea fits to the previously documented highly competitive educational systems of East Asia (Cheng, 2017; Gradisar et al., 2011; Hertog & Zhou, 2021). By contrast, socializing activities in the Netherlands were more common during the two hours before going to sleep. While unfortunately our data do not offer harmonized health measures, we see such country variations in adolescent time use before sleep onset as a first key step to guide future research on how adolescents' activity patterns relate to sleep quality and health outcomes across national contexts.

This study also presents some convergence in adolescent sleep across countries. Sleep patterns differed markedly between schooldays and non-schooldays in most countries, with adolescents showing longer sleep duration and later sleep times during non-schooldays, in line with literature on adolescent sleep (Carskadon, 2011; Crowley et al., 2007). Additionally, across countries, older adolescents showed a drop in sleep duration, compared to their younger counterparts. The drop in sleep duration during adolescence is a very well-known phenomenon, which is caused by a conflict between the late adolescents' sleep times and the early school starting times (Crowley et al., 2018). Our data show that early school starting times remain a worldwide problem, which should be addressed to promote sleep and health of especially older adolescents (Au et al., 2014). Our analyses estimating differences between boys and girls in sleep patterns were partly mixed. While boys slept more than girls in most countries, such gender differences were small in most countries.

Our findings have significant policy and practical implications by revealing distinct patterns of adolescent sleep across countries with dissimilar policy and cultural traditions. We observe

that South Korea and Spain exhibit the highest levels of insufficient sleep among adolescents (69% in South Korea and 42% in Spain on schooldays). However, the reasons behind such high rates of insufficient sleep seem to be very different. South Korean adolescents may experience reduced sleep due to extensive study hours driven by their competitive societal norms, emphasizing academic achievement as a measure of success (Dong-Il & Wi-Young, 2014; Rhie et al., 2011). Conversely, Spanish adolescents face similar sleep deficits, which may stem partly from culturally ingrained late schedules (e.g. mealtimes, leisure activities) resulting in late sleep times, which clash with the still relatively early school start times (9 am) (Gracia & García-Román, 2018). Addressing these issues requires policy interventions on daily schedules. This could involve adjusting school opening hours, discouraging late-night events or meetings, or promoting a balanced distribution of media programmes throughout the day. In contrast, South Africa, the sole African country from our study, exhibits sleep patterns closer to recommended guidelines by experts (Paruthi et al., 2016). These findings underscore the influence of societal contexts on adolescent well-being, particularly concerning sleep and bedtime practices. While our study does not prescribe specific policies or interventions, it suggests that adolescent sleep behaviour is partly driven by cross-country variations in policy and cultural contexts.

We should acknowledge some shortcomings in our study that we hope future studies will be able to address. First, while our paper reports cross-national variations in adolescent sleep patterns with accurate time-diary data, our data do not allow exploring the societal and cultural factors behind such variations. Scholars should dig deeper into the role of societal factors that determine adolescent sleep behaviour, for example by examining cross-nationally the role of school organizations or parental control in influencing sleep patterns and other related factors, such as school performance (Biller et al., 2022; Yip et al., 2022). Second, while our time-diary approach brings a novel 24-hour look at the multiple ways in which adolescents engage in activities during the evening, we were not able to provide a precise picture of the context and content of these activities prior to sleep onset. We hope future research will complement our time-diary approach to provide a precise understanding of these processes prior to sleep onset time. Third, our study has not been able to examine the causal links between activity patterns and adolescent sleep patterns, given the cross-sectional design adopted. Finally, future studies should also consider other sociodemographic information besides age and gender that is included in time use surveys, as for example household composition.

To conclude, this study brings a new time-use approach that is critical to study how adolescent sleep patterns are shaped by national contexts. Our results indicate that countries with dissimilar policy and cultural contexts differ remarkably, not only in the duration and timing of adolescent sleep, but also in the activities in which teenagers engage in the moments before their sleep onset. More studies are needed to understand the explanatory mechanisms of heterogeneous patterns in adolescents' sleep.

Disclosure statement

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