



# Dual Trajectories of Sleep Duration and Cigarette Smoking during Adolescence: Relation to Subsequent Internalizing Problems

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## Abstract

Decreasing sleep duration and increasing cigarette smoking of adolescents are major public health concerns. However, research examining connections between the developmental trajectories of the outcomes that are evolving contemporaneously and their relation to long-term outcomes is still lacking. This study examined distinct trajectories of sleep duration and cigarette smoking during adolescence, associations between these trajectories, and links with internalizing problems during young adulthood. Data were collected from 2510 adolescents who participated in a longitudinal study spanning from 2006 through 2014 in northern Taiwan. Group-based dual trajectory modeling was used to examine the dynamic relationships between sleep duration and cigarette smoking trajectories during adolescence. Multiple linear regression was used to understand the association between the distinct trajectories and subsequent internalizing problems. Three sleep duration trajectories (short decreasing, typical sleep, and long sleep) and three cigarette smoking trajectories (nonsmokers, late increasing, and escalating smokers) were identified. We found significant inter-relationships for sleep duration and cigarette smoking trajectories during adolescence; all atypical sleep duration trajectories conferred increased risks of increased cigarette smoking and vice versa. In addition, the effects of sleep duration and cigarette smoking on later internalizing problems were found to vary by sex and trajectory patterns. These results provide insight regarding the co-development of sleep duration and cigarette smoking trajectories during adolescence. We also highlight the different roles of sleep duration and cigarette smoking trajectories and their relation to internalizing problems of young adulthood.

**Keywords** Sleep duration · Cigarette smoking · Dual trajectories · Internalizing problems

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## Introduction

Adolescence is a period during which many health and behavioral problems occur because of radical changes in hormonal, physical, and social functioning. Insufficient sleep is one of the common health risks that is often observed during adolescence (Owens 2014). Inadequate sleep duration has also been particularly linked with substance use, including cigarette smoking (Gromov and Gromov 2009). Theoretically, sleep loss may increase the likelihood of cigarette smoking because of the potential of nicotine to reduce subjective sleepiness (Hamidovic and de Wit 2009). Sleep loss may also impair several cognitive abilities (Louca and Short 2014), which could further weaken the ability of smokers to refrain from smoking. Conversely, nicotine has a stimulant effect, which may increase arousal and difficulty initiating sleep (Zhang et al. 2006). Habitual smokers often experience acute withdrawal at night, leading to sleep disturbance and awakening (Colrain et al. 2004). Together, this evidence suggests a plausible link between sleep and cigarette smoking.

To better understand the nature of their development and to pinpoint targets for intervention, research has called for the identification of multiple developmental trajectories of sleep duration and cigarette smoking as well as their concomitant relationships (Magee et al. 2014). In addition, because the co-occurrence of inadequate sleep and smoking may further worsen health outcomes of adolescents, examining the co-occurring trajectories of these two problems in relation to later outcomes is warranted.

### **Developmental Trajectories of Sleep Duration in Adolescents**

Heterogeneous trajectories of sleep duration have been identified for children and adolescents. However, most studies exploring distinct trajectories of sleep duration have focused on the developmental period of childhood and generally found three to four trajectories (Magee et al. 2014; Seegers et al. 2011; Touchette et al. 2008, 2009). For example, Magee et al. (2014) identified four distinct sleep trajectories for children followed-up across four time points from age 0–1 years to 6–7 years: typical sleepers, initially short sleepers, poor sleepers, and persistent short sleepers. In another study, three distinct trajectories of sleep duration were identified for children followed-up from age 10 to 13 years: short sleepers, 10.5-h sleepers, and 11-h sleepers (Seegers et al. 2011). Despite the recognition of different patterns of sleep duration for children, information regarding the developmental nature of sleep duration during adolescence is currently lacking.

### **Developmental Trajectories of Cigarette Smoking for Adolescents**

In Taiwan, the Tobacco Hazards Prevention Act in 1997 and the later 2009 amended Act prohibits persons younger than 18 years from smoking, extends smoke-free areas, and totally bans tobacco advertisements. Although the enactment of these legislations regarding tobacco control helps decrease the prevalence of cigarette smoking, the age-specific prevalence of cigarette smoking still shows an increased trend with age (Health Promotion Administration 2017). Alarming, the prevalence of cigarette smoking reaches 30% when adolescents transitioned to young adulthood (Health Promotion Administration 2017), suggesting a need to better understand the developmental patterns of cigarette smoking during adolescence so that tailored interventions can be developed and implemented early.

The distinct trajectories of cigarette smoking over time have also been identified by several longitudinal studies, but the samples included mostly white participants (Brook et al. 2014; Lee et al. 2016; Orpinas et al. 2016). Four different patterns were observed in these studies: abstainers; continuous smoking initiated during early adolescence that progressed to

heavy smoking throughout the study period (e.g., continuous users, heavy smokers); smoking initiated during late adolescence and maintained (e.g., late starters, late escalating); stable but infrequent smoking (e.g., experimenters, occasional smokers). Although these studies provided insights into trajectories of cigarette smoking, the nature of cigarette smoking for Asian adolescents requires further study. Because adolescent behaviors tend to depend on their norms and those of their cultural group (Jessor et al. 2003), different trajectories may emerge between Asian and Western countries. Therefore, understanding trajectories of cigarette smoking in Taiwan is warranted, and the results can provide valuable information for tobacco prevention and intervention.

### **Inter-Relationships between Sleep Duration and Cigarette Smoking Trajectories**

Recent research has shifted to examine possible inter-relationships between sleep duration and cigarette smoking. Longitudinal studies have confirmed that cigarette smoking predicts the development and persistence of frequent sleep problems for adolescents (Patten et al. 2000) as well as insomnia later during adulthood (Lee et al. 2016). However, the reversed association has seldom been examined. Currently, only a few studies have investigated the inter-relationship between sleep problems and substance use, and the results were mixed (Pasch et al. 2012; Pieters et al. 2015). Evidence also suggests that the association between sleep duration and cigarette smoking could be influenced by a third variable such as hormonal and socio-environmental changes (Savage et al. 2017).

In addition, no study has jointly examined how different trajectories of cigarette smoking and sleep duration co-develop during adolescence. It is currently unknown whether change in sleep duration is associated with concomitant patterns of desistence, maintenance, or escalation of cigarette smoking. By examining the co-development of sleep duration and cigarette smoking across various trajectory groups, the results will permit us to comprehend the multidimensional and dynamic association between the two outcomes. A better understanding of the distinct patterns of comorbidity between sleep problems and cigarette smoking could also provide useful information for intervention and prevention programs regarding co-occurring risks.

### **Sleep Duration and Cigarette Smoking in Relation to Internalizing Problems**

Furthermore, some investigators have specifically examined the relation between different patterns of sleep duration or cigarette smoking and health problems (Seegers et al. 2011; Brook et al. 2007). Evidence have shown that adolescents in the early start and continuous cigarette smoking group were more likely to become alcohol-dependent and drug-dependent

during young adulthood than those in other groups (Brook et al. 2007). However, research has not examined the effects of dual trajectories of sleep duration and cigarette smoking during adolescence on the subsequent risk of internalizing problems during young adulthood.

The association among sleep duration trajectories, cigarette smoking trajectories, and internalizing problems, however, may be confounded by several covariates. For example, low parental education levels, single-family households, and low family economic status have been associated with increased risks of short sleep (Troxel et al. 2014), cigarette smoking (Wallace et al. 2009), and internalizing problems (Goodman and Huang 2002). Stressful life events and pubertal development are important factors of sleep health (Ly et al. 2015; Randler and Bilger 2009), substance use (Tyas and Pederson 1998; Savage et al. 2017), and internalizing problems (Low et al. 2012; Ullsperger and Nikolas 2017). In addition, it has been suggested that sleep debt may represent the sleep curtailment or inadequate amount of sleep adolescents get on school nights (Yang et al. 2005), with higher levels of sleep debt suggest greater sleep deprivation on school days. In fact, research has found that adolescent with sleep debt reports shorter sleep duration (Warner et al. 2008), more frequent use of tobacco (Zhang et al. 2017), and higher levels of internalizing problems (Sivertsen et al. 2014) than those without sleep debt.

## The Current Study

To advance prior research, this study aimed to examine 1) the distinct trajectories of sleep duration and cigarette smoking during adolescence, 2) dynamic inter-relationships of the trajectories of sleep duration and cigarette smoking, and 3) prospective links between the dual trajectories of sleep duration and cigarette smoking and later internalizing problems. Because the evidence suggests sex differences in the manifestation and prevalence of various psychiatric disorders in youths (Van Damme et al. 2014), we further examined whether the effects of sleep duration and cigarette smoking trajectories on the outcomes differ across sexes.

We hypothesized that there would be two to four different trajectories of sleep duration during adolescence from ages 12 to 18 years. Specifically, based on past research, in addition to a typical group that had gradual decreases in sleep duration over time, we expected that there would be other groups that varied in average sleep hours and had different decelerating, accelerating, or persistent patterns of sleep duration (e.g., short increasing/decreasing, persistent good/poor sleepers). Regarding cigarette smoking trajectories, we hypothesized that adolescents would follow different trajectories of smoking, with one group consisting of a large proportion of adolescents reporting no or sporadic smoking and at least one additional group that differed regarding levels of initiation and

rates of escalation (e.g., late starters, chronic users, escalators). We also expected that there would be associations between the developmental trajectories of sleep duration and cigarette smoking during adolescence such that adolescents in the shorter sleep duration trajectories would be more likely to be in the trajectory groups with higher levels of smoking as compared to others in the typical sleep duration trajectory. Finally, we hypothesized that adolescents with an atypical sleep trajectory or escalating smoking trajectory would show increased levels of internalizing problems compared to youths in other groups.

## Methods

### Data and Sample

The study data came from the Child and Adolescent Behaviors in Long-term Evolution (CABLE) project (Yen et al. 2002), a multi-wave longitudinal study of health and risk behaviors for children and adolescents. The 1st and 4th grade students were sampled from 18 elementary schools located in one rural area (Hsingchu County) and one urban area (Taipei City) in northern Taiwan. A total of 16 waves of data were collected annually from 2001 to 2016. Informed consent was obtained from the child's parent or guardian at baseline. The CABLE study was approved by the Internal Review Board of the National Health Research Institutes (approval code: EC9009003; EC1041109-E). The current study used data from waves 6 through 14, which included measurements assessed from participants during their developmental stages of adolescence and young adulthood. Response rates ranged between 67.11% and 84.69% during waves 6 through 14. The study sample included 2510 participants who were 11 or 12 years old in 2006 and had completed at least four waves of data collection. Of those in the analysis sample, 51% participated in all 9 waves, and 17.41%, 10.12%, 8.96%, 7.05%, and 5.46% participated in only 8, 7, 6, 5, and 4 waves, respectively. There was no significant difference regarding covariates, sleep duration, cigarette smoking, or internalizing problems between participants who dropped out of the study for one or more waves and those who participated in all nine waves.

### Measures

**Sleep Duration** Sleep duration was estimated as the time spent in bed (TIB) between bedtime and waking time (Seegers et al. 2011). During annual data collection in the fall semester of the school year from 2006 to 2013, adolescents were asked to answer two questions regarding the approximate time they had gone to bed and woke up on weekdays and weekends during the past month. The sleep times reported were screened

for extreme values and coded as missing if an adolescent reported sleep times that were 3 standard deviations higher or lower for age-specific and gender-specific mean hours of sleep (Mitchell et al. 2013). To enable comparisons with previous research, a weighted average of weekday and weekend sleep duration was calculated for each adolescent by using the recommended formula:  $[(\text{weekday sleep duration} \times 5) + (\text{weekend sleep duration} \times 2)/7]$  (Magee et al. 2014).

**Cigarette Smoking** Adolescents were asked to indicate the frequency of smoking during each assessment from 2006 to 2013: “have you ever smoked a cigarette (even one puff)?” Cigarette smoking at each time point was then measured with a scale coded as follows: 1 = never smoked, even a puff; 2 = ever puffed but no smoking during the past year; 3 = smoked during the past year but not during the past month; 4 = smoked once or twice during the past month; 5 = smoked many times during the past month; and 6 = smoked every day during the past month. Higher values indicated higher levels of cigarette smoking. The validity of this item as a measure of cigarette smoking has been demonstrated previously (Andrews et al. 2008).

**Internalizing Problems** The Internalizing Problem Behavior Scale, includes subscales of depressive symptoms, social anxiety, and social loneliness, was measured in 2014. Depressive symptoms were assessed by asking adolescents whether they had experienced any of the six depressive symptoms (e.g., “lost appetite,” “felt sad,” “cried for no reason”) during the past 2 weeks. Social anxiety was measured using seven items (e.g., “I get nervous when I meet new people,” “I worry about being teased,” “I am afraid of talking to people I do not know”). Social loneliness was assessed using six items (e.g., “have nobody to talk to,” “feel lonely,” “feel left out”). All items were measured with a 3-point frequency scale ranging from 1 (never) to 3 (many times). A total of 19 items were averaged to create an internalizing problem score, with a higher score indicating a higher level of internalizing problems. Cronbach’s  $\alpha$  was 0.93 in the current study. This 3-factor Internalizing Problem Behavior Scale has been validated for its psychometric properties by confirmatory factor analysis and was shown to have acceptable reliability and validity (Yu et al. 2009). Specifically, in study of Yu et al. (2009), indicator reliability was examined by squaring the standardized factor loadings obtained; composite reliability was tested by computing composite reliability index for each latent factor; convergent validity was assessed by reviewing the  $t$  tests for the factor loadings, and discriminant validity was determined by performing the chi-square difference test and the confidence interval test.

**Covariates** The analyses controlled for the following covariates.

**Biological sex.** Biological sex was coded such that the reference group was male.

**Age.** Age was calculated based on participants’ dates of birth.

**Parental education.** Participants’ reports of the highest level of education attained by each parent in 2007 ranged from 0 (junior high school or less) to 2 (college or more).

**Family structure.** Family structure was measured in 2006 and coded as follows: 0 = two-parent household and 1 = single-parent household.

**Family economic status.** Family economic status was measured by asking participants about perceptions of their family economic situation in 2007. Response categories ranged from 1 (low) to 3 (high).

**Stressful life events.** Fourteen items (e.g., “broken romantic relationship,” “serious illness,” “changed residence”) were used to measure stressful life events in 2006. Response categories (1 = yes and 0 = no) were summed as a total score of stressful life events, with higher scores indicating more stressful life events.

**Pubertal development.** Based on items adapted from the Pubertal Development Scale (Petersen et al. 1988), adolescents were asked to rate the amount of development they had experienced with respect to physical characteristics in 2006. Response options ranged from 1 (no development) to 4 (development completed). Five and four items regarding physical characteristics were averaged to create pubertal development scores for males and females, respectively. Higher scores indicated more advanced pubertal development. Cronbach’s  $\alpha$  was 0.61 for the male scale and 0.64 for the female scale.

**Sleep problems.** Six items adapted from the Pittsburgh Sleep Quality Index (Buysse et al. 1989) regarding adolescent experiences with sleep problems during the past month (e.g., “having trouble falling asleep,” “having sleep disruption,” “waking in the middle of the night or early morning”) were used to assess sleep problems in 2009. Items were measured using a 5-point scale and were averaged to create a sleep problem score; higher scores indicated more sleep problems. Cronbach’s  $\alpha$  was 0.66.

**Sleep debt.** Sleep debt was calculated as weekend sleep duration minus weekday sleep duration in 2006 (Spilsbury et al. 2007).

**Prior internalizing problems.** The same scale as presented in the previous section was used to assess prior internalizing problems in 2006. Cronbach’s  $\alpha$  was 0.90.

## Analytical Strategy

The analysis of the current study involved three main steps. During the first step, group-based trajectory modeling was applied to identify the distinct developmental trajectories of sleep duration and cigarette smoking during adolescence



using SAS Proc Traj (SAS Institute Inc. 2011). We used a censored normal model to estimate both trajectories of sleep duration and cigarette smoking and the optimal number of groups to be included in the model was chosen based on several criteria, including: Akaike information criterion (AIC); Bayesian information criterion (BIC); log Bayes factor ( $2\Delta\text{BIC}$ )  $>10$ ; trajectory group size  $\geq 5\%$  of the sample; average posterior probability (AvePP)  $>0.70$ ; and model interpretability (Nagin 2005). Models with an optimal number of groups were then refined to determine the preferred polynomial order that best characterized the shape of each trajectory group over time. Individuals were assigned to the group that conformed best to their observed behaviors according to the maximum posterior probability of group membership.

During the second step, a dual trajectory model of sleep duration and cigarette smoking was estimated. Following the recommendations of Jones and Nagin (2007), the dual model was estimated based on the number and shapes of the best-fitting trajectory models found during the first step of analysis. Key outputs of a dual model were the joint and conditional probabilities of trajectory membership that were useful for describing the developmental overlap between two distinct but related behaviors. Based on the results from group-based dual trajectory modeling, we further conducted a logistic regression analysis to confirm whether the observed association between sleep duration and cigarette smoking trajectories remained similar after adjustment for important confounders.

Finally, multiple linear regressions were conducted to examine the effects of sleep duration and cigarette smoking trajectories on internalizing problems after controlling for individual covariates. To perform these analyses, we relied on the posterior probabilities of group membership based on the best fitting model to account for classification uncertainties when estimating future outcomes (Dong and Krohn 2016). Missing data for covariates were handled by multiple imputation using SAS PROC MI (SAS Institute Inc. 2011). Ten sets of missing values were imputed using multiple-chain Markov Chain Monte Carlo methods. Models were fit to each of the 10 imputed datasets, and the results were combined using SAS PROC MIANALYZE (SAS Institute Inc. 2011).

## Results

### Sample Characteristics

Table 1 lists demographic characteristics of the study sample. Approximately half of the participants were female (49.16%). The mean age at baseline (year 2006) was 11.72 years. Most of the participants reported that the highest parental education level was senior high school (51.72% and 59.72% for father and mother, respectively). Only 10.97% of the participants were from a single-parent household, and 8.83% indicated

that their family economic status was low. The average sleep duration decreased over time from 506.08 min to 444.08 min during the study period. However, the frequency of cigarette smoking increased as adolescents aged.

### Sleep Duration Trajectories

Online Resource 1 presents the goodness-of-fit indices for models with different trajectory groups. A model with three groups was chosen because it exhibited higher values of AvePP for each group than did the four-group model (range, 0.83–0.86  $>$  0.74–0.84) and because it captured the essential features of the data in a more parsimonious, comprehensible, and interpretable manner. Figure 1 depicted the three sleep duration trajectories. The first trajectory ( $n = 506$ ; 20%), “short declining,” comprised participants who had inadequate sleep (less than 8 h) at the beginning of the study and showed a rapid decline in sleep duration during adolescence. The second trajectory, “typical sleep,” was the largest group ( $n = 1659$ ; 66%) and was characterized by a gradual decline in sleep duration with the rate of decline slowed by age. The final trajectory ( $n = 345$ ; 14%), “long sleep,” comprised adolescents who consistently had relatively long sleep durations ( $>8.5$  h) during adolescence.

### Cigarette Smoking Trajectories

Because most adolescents have not started smoking at age 12 years (92%), we only included data regarding tobacco use from age 13 to 18 years when modeling smoking trajectories to improve parameter estimation. Based on the fit indices (Online Resource 1), the three-group model was considered optimal for cigarette smoking trajectories (AvePP  $>0.90$  for each group), which were displayed in Fig. 1. Group 1 ( $n = 1772$ ; 71%), “nonsmokers,” comprised adolescents who indicated no cigarette smoking throughout the study period or very low levels of sporadic tobacco use. Group 2 ( $n = 560$ ; 22%), “late increasing,” consisted of adolescents who had a low frequency of cigarette smoking before age 15 years but increased use of tobacco during late adolescence. Group 3 ( $n = 178$ ; 7%), “escalating smokers,” exhibited a low likelihood of cigarette smoking at age 13 years but an escalating likelihood of use during adolescence.

### Dual Trajectories of Sleep Duration and Cigarette Smoking

Results of the dual trajectory analysis are shown in Table 2. The upper section of Table 2 shows the joint probability of membership in a specific trajectory of sleep duration and a specific trajectory of cigarette smoking (the 12 joint probabilities sum to 1). The highest proportion of adolescents were those who never smoked or used tobacco sporadically and

**Table 1** Descriptive statistics for study variables ( $N = 2510$ )

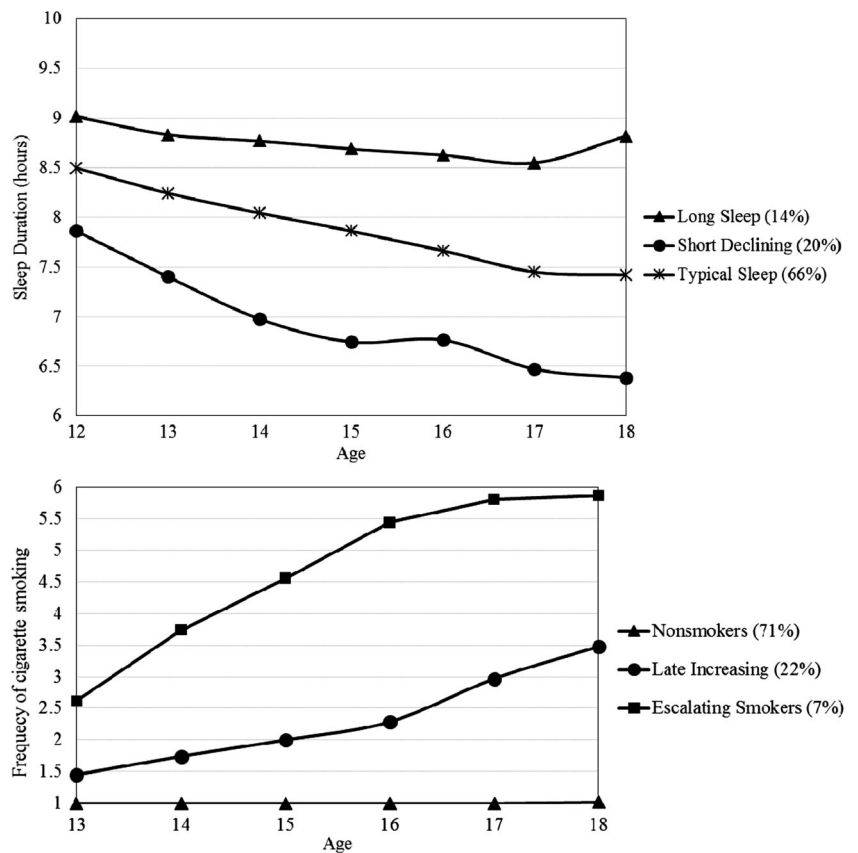
Characteristics	n	%	Mean	SD	Range
Female	1234	49.16			
Father's education level					
Junior high or less	288	14.35			
Senior high or vocational school	1038	51.72			
College or more	681	33.93			
Mother's education level					
Junior high or less	254	12.60			
Senior high or vocational school	1204	59.72			
College or more	558	27.68			
Family structure					
Two-parent family	1988	89.03			
Single-parent family	245	10.97			
Family economic status					
Low	197	8.83			
Medium	997	44.67			
High	1038	46.51			
Baseline age (year)	2510		11.72	0.45	11–12
Stressful life event	2232		0.89	1.15	0–11
Pubertal development	2237		1.55	0.50	1–3.5
Sleep problems	2212		1.49	0.45	1–5
Sleep debt					
Weekday sleep duration (minutes)	2209		495.25	51.98	285–690
Weekend sleep duration (minutes)	2209		555.07	91.79	60–1200
Prior internalizing problems	2237		1.39	0.34	1–2.74
Internalizing problems	1886		1.38	0.37	1–3
Sleep duration (minutes)					
Age 12	2218		506.08	51.32	270.71–711.43
Age 13	2191		488.88	52.02	238.57–768.57
Age 14	2141		475.21	56.76	214.29–720.00
Age 15	1983		465.12	56.30	150.00–720.00
Age 16	2226		456.94	53.93	257.14–711.43
Age 17	2258		444.21	58.77	210.00–642.86
Age 18	2077		444.08	69.68	175.71–720.00
Frequency of cigarette smoking					
Age 12	2239		1.12	0.51	1–6
Age 13	2168		1.21	0.72	1–6
Age 14	2113		1.31	0.92	1–6
Age 15	2028		1.41	1.10	1–6
Age 16	2031		1.50	1.27	1–6
Age 17	2079		1.65	1.46	1–6
Age 18	1883		1.77	1.60	1–6

those with typical sleep (45.1%), followed by the “non-smokers” and “short declining” trajectory groups (14.1%).

The middle section of Table 2 presents the probabilities of membership in each of the three sleep duration trajectories based on membership in each cigarette smoking trajectory (each row sums to 1). Adolescents in the “nonsmokers” trajectory of cigarette smoking were most likely to belong to the

“typical sleep” (65.4%) and least likely to belong to the “long sleep” (14.1%) trajectory of sleep duration. Compared to adolescents in the “nonsmokers” trajectory, those followed the “late increasing” trajectory had an increased probability of belonging to the “short declining” group (25.5%) and “long sleep” group (19.1%). For adolescents in the “escalating smokers” trajectory, the probabilities of having “typical sleep”

**Fig. 1** Distinct developmental trajectories of sleep duration (top) and cigarette smoking (bottom) during adolescence (age, 12–18 years)



decreased to 47.3%, whereas the probabilities of having “long sleep” largely increased (32.8%).

The bottom section of Table 2 shows the reverse set of conditional probabilities (each column sums to 1). As expected, adolescents following the “typical sleep” trajectories of sleep duration were most likely to follow the “nonsmokers”

trajectory of cigarette smoking (73.18%). For adolescents belonging to the “short declining” sleep trajectory, the probabilities of being “nonsmokers” decreased to 65.52% and the probabilities of being in the other two smoking trajectories increased. Moreover, the probability of being classified as “escalating smokers” (16.76%) was highest for adolescents in the “long sleep” trajectory.

**Table 2** Inter-relationship of sleep duration and cigarette smoking during adolescence

Smoking group	Sleep duration group		
	Typical sleep	Short declining	Long sleep
Probability of joint trajectory group membership			
Nonsmokers	45.10%	14.10%	9.70%
Late increasing	12.50%	5.70%	4.30%
Escalating smokers	4.10%	1.70%	2.80%
Probability of sleep duration conditional on smoking			
Nonsmokers	65.40%	20.50%	14.10%
Late increasing	55.30%	25.50%	19.10%
Escalating smokers	47.30%	19.90%	32.80%
Probability of smoking conditional on sleep duration			
Nonsmokers	73.18%	65.52%	57.62%
Late increasing	20.22%	26.57%	25.61%
Escalating smokers	6.60%	7.90%	16.76%

Table 3 presents the results for the association between sleep duration and cigarette smoking trajectories after adjustment for covariates. The expected risk of belonging to the “late increasing” smoking trajectory relative to the “nonsmokers” trajectory was higher for adolescents who were in the “short declining” or “long sleep” trajectory than for those in the “typical sleep” trajectory (odds ratio, 1.63 and 1.67, respectively; both  $p < 0.001$ ). After adjusting for confounding factors, the odds ratio for belonging to the “escalating smokers” group versus the “nonsmokers” group was 1.70-times ( $p < 0.001$ ) higher in the “short declining” trajectory and 4.81-times ( $p = 0.02$ ) higher in the “long sleep” trajectory compared with the “typical sleep” trajectory.

**Relations between Trajectories and Subsequent Internalizing Problems**

The results of a multivariate linear regression model (Table 4) show that adolescents in the “short declining”

**Table 3** Association between sleep duration and cigarette smoking trajectories adjusted for covariates

Trajectory (N = 2510)	Late increasing smokers vs Nonsmokers		Escalating smokers vs Nonsmokers	
	Odds Ratio	<i>p</i>	Odds Ratio	<i>p</i>
Sleep duration trajectories (ref.: typical sleep)				
Short declining	1.63	<0.001	1.70	<0.001
Long sleep	1.67	<0.001	4.81	0.02

Model was adjusted for sex, age, parental education, family structure, family economic status, stressful life events, pubertal development, sleep debt, and sleep problems

sleep trajectory had significantly higher levels of internalizing problems than those in the “typical sleep” trajectory ( $B = 0.05$ ;  $p < 0.01$ ). Conversely, those in the “long sleep” trajectory showed lower levels of internalizing problems ( $B = -0.07$ ;  $p < 0.05$ ). Regarding the association between smoking trajectories and internalizing problems, adolescents in the “escalating smokers” trajectory had significantly lower levels of internalizing problems than those in the “nonsmokers” trajectory ( $B = -0.08$ ;  $p < 0.05$ ).

We further tested whether the effects of sleep and smoking trajectories on internalizing problems differed across sex by conducting the models separately for males and females. As shown in Table 4, although male adolescents who followed the “short declining” sleep trajectory had significantly higher levels of internalizing problems than those in the “typical sleep” trajectory ( $B = 0.07$ ;  $p < 0.05$ ), the negative effects of being in the “short declining” sleep trajectory were not significant for females. In contrast, being in the “long sleep” trajectory relative to being in the “typical sleep” trajectory was

**Table 4** Trajectories of sleep duration and cigarette smoking during adolescence predicting internalizing problems during young adulthood

Variables	All (N = 2510)		Males (n = 1276)		Females (n = 1234)	
	B	SE	B	SE	B	SE
Intercept	0.97***	0.22	0.68*	0.31	1.21**	0.32
Sex (ref: female)	-0.01	0.02	—	—	—	—
Age	-0.02	0.02	0.00	0.03	-0.04	0.03
Father’s education level (ref: junior high or less)						
Senior high or vocational school	0.02	0.03	0.01	0.05	0.03	0.04
College or more	0.05	0.04	0.04	0.05	0.06	0.06
Mother’s education level (ref: junior high or less)						
Senior high or vocational school	0.00	0.03	-0.01	0.04	0.00	0.04
College or more	0.05	0.04	0.08	0.05	0.02	0.06
Single-parent family (ref: two-parent family)	-0.02	0.03	-0.03	0.04	0.00	0.04
Family economic status (ref: low)						
Medium	-0.05	0.03	-0.11*	0.05	-0.01	0.04
High	-0.10*	0.03	-0.12*	0.05	-0.09†	0.04
Stressful life event	0.01	0.01	0.02†	0.01	-0.01	0.01
Pubertal development	0.05*	0.02	0.10*	0.04	0.03	0.03
Sleep problems	0.12***	0.02	0.11***	0.03	0.12***	0.03
Sleep debt	0.00	0.00	0.00†	0.00	0.00	0.00
Prior internalizing problems	0.28***	0.03	0.30***	0.04	0.28***	0.04
Sleep duration trajectories (ref: typical sleep)						
Short declining	0.05**	0.02	0.07*	0.03	0.03	0.03
Long sleep	-0.07*	0.02	-0.02	0.03	-0.13***	0.04
Smoking trajectories (ref: nonsmokers)						
Late increasing	-0.03	0.02	-0.05†	0.03	-0.01	0.03
Escalating	-0.08*	0.03	-0.10**	0.04	-0.06	0.08

B unstandardized regression coefficients, SE standard errors, — not applicable

\*\*\*  $p < 0.001$ ; \*\*  $p < 0.01$ ; \*  $p < 0.05$ ; †  $p < 0.10$



significantly associated with lower levels of internalizing problems in females ( $B = -0.13$ ;  $p < 0.001$ ) but not in males. Sex differences also emerged for the association between smoking trajectories and internalizing problems such that the influences of being in the escalating smoking group relative to being in the nonsmokers group on internalizing problems was only significant for males ( $B = -0.10$ ;  $p < 0.01$ ).

Several covariates that were also significantly associated with internalizing problems and similar results were obtained from the overall sample and sex-stratified sample (Table 4). Specifically, adolescents from families with high economic status had significantly lower levels of internalizing problems than those from families with low economic status. Conversely, more advanced pubertal development, more sleep problems, and higher levels of prior internalizing problems were associated with elevated levels of subsequent internalizing problems. Nevertheless, controlling for covariates did not alter our findings. The fully adjusted model had essentially the same pattern of findings as the unadjusted model (not shown).

## Discussion

This study represents the first investigation of developmental trajectories of sleep duration throughout adolescence. Similar to the other national longitudinal study of adolescent sleep duration (Maslowsky and Ozer 2014), the sleep duration observed in the majority of the adolescents studied (66%) followed a gradual decrease across adolescence. A substantial number of adolescents in the current sample (20%) reported short sleep (less than 8 h) at age 12 years and showed a rapid, marked decrease in sleep duration during the study period. The current results were also consistent with those of a number of previous studies indicating that the development of sleep duration decreased with age during adolescence (Maslowsky and Ozer 2014; Williams et al. 2013; Leger et al. 2012). Using longitudinal analysis, we further show that there is a habitual, rather than periodic, long sleep pattern for adolescents with an average of 9 h sleep per night from age 12 to 18 years (14%).

Consistent with perspectives that the developmental course of cigarette smoking initiation and progression may not follow the same trajectory pattern among adolescents (Xie et al. 2013), three developmental trajectories of cigarette smoking were identified in the current study. As expected, the nonsmokers group was the largest segment of the studied sample, reflecting current national epidemiological data of youth who never smoked (Huang et al. 2013) and concordant with prior longitudinal studies (Orpinas et al. 2016; Lee et al. 2016). Identifying the other two distinct cigarette smoking trajectories with different timing and rates of escalation further provides valuable information for intervention. Specifically, because levels of cigarette smoking markedly increased from

age 16 years for adolescents in the late increasing smoking trajectory, early intervention during childhood and early adolescence may be important for individuals whom tend to follow this group. In addition, because the speed of escalation is considered an indicator of the progression to heavy smoking and nicotine dependence (Karp et al. 2005), particular intervention efforts should be applied to individuals whom are likely to follow an escalating course of smoking, which arguably may prevent them from moving to a more advanced stage of tobacco use.

Examination of dual trajectories of sleep duration and cigarette smoking in this study confirmed previous findings of reciprocal relationships between cigarette smoking and sleep problems (Pasch et al. 2012). Specifically, compared to “typical sleepers,” adolescents who followed the “short declining” trajectory had increased risks of becoming “escalating smokers,” and this was consistent with previous findings (Pasch et al. 2012; Terry-McElrath et al. 2016). Similarly, the observed probabilities of being in the “short declining” trajectory were higher for “escalating smokers” than for “nonsmokers.” We further demonstrated that those with longer sleep duration were also at increased risk for cigarette smoking. Despite studies of adult populations have found both short sleep and long sleep were associated with cigarette smoking (Ryu et al. 2011; Swinkels et al. 2013), the relationship between long sleep and cigarette smoking for adolescents, however, has seldom been examined.

Given that people with long sleep duration show distinct patterns of socio-demographic characteristics, lifestyle factors, and comorbid diseases that are different from those with an appropriate sleep duration (Krueger and Friedman 2009; Wang et al. 2017), it is likely that these differential characteristics may place adolescents with prolonged sleep at higher risks for cigarette smoking. It is also possible that problems associated with long sleep (Grandner and Kripke 2004), such as feeling unrefreshed and daytime sleepiness, help contribute to the increased risks of cigarette smoking. However, it is worth noting that long sleep may not necessarily represent a health risk for adolescents despite the positive association observed between long sleep and smoking because the current study also found that long sleep was potentially protective against internalizing problems. Due to the scarce research examining the association between long sleep duration and cigarette smoking for adolescents, more research is needed to confirm the current findings and to understand the underlying mechanisms.

Our results extend previous findings (Chaput et al. 2016) by showing that the associations between sleep duration and internalizing problems differed by patterns of sleep duration trajectories and sex of adolescents. Specifically, compared to those with typical sleep, male adolescents with short declining sleep had significantly higher levels of internalizing problems. In contrast, female adolescents who belonged to the long sleep

trajectory group reported significantly lower levels of internalizing problems later in life than others in the typical sleep trajectory. Prior research regarding sex differences in the links between sleep and health outcomes in adolescents was scarce and yielded mixed results (Danielsson et al. 2013; Jiang et al. 2015; Sivertsen et al. 2014). Potential sex differences in the association being examined may be due to the differences in sleep characteristics. Compared to girls, boys generally have more sleep problems (Paavonen et al. 2000), and these sex differences may affect how sleep duration impacts the internalizing problems differently for boys and for girls. Additionally, the higher propensity to seek support when encountering sleep problems in females than in males and thereby get treatment (Liu et al. 2016) may help decrease the negative impact of short sleep on internalizing problems in females.

Inconsistent with prior findings that long sleep duration is detrimental to health (Wang et al. 2017; Patel et al. 2006), we observed that females in the long sleep trajectories reported significantly lower levels of internalizing problems than other females in the typical sleep group. Several explanations were proposed for the discrepancies. First, the existing research focused exclusively on adult populations and results were limited to the links between long sleep and physical health or behavioral problems. Therefore, whether long sleep duration contributes to increased or decreased levels of internalizing problems for adolescents remains uncertain. In addition, it is also unknown whether the effects of long sleep on internalizing problems may differ by sex. Different mechanisms underlying the pathways from long sleep duration to varying health outcomes across sexes may exist and may lead to different strengths of associations. In addition, junior and senior high school students in Taiwan are required to spend considerable time completing school assignments and preparing for entrance examines, thereby causing short sleep duration and elevated levels of life stress (Gau and Soong 1995). The adolescents who have long sleep duration, particularly females, may have different lifestyles that lead to lower levels of internalizing problems.

We also found sex differences in the relationship between smoking trajectories and internalizing problems. In line with previous findings (Savage et al. 2016; Cloutier et al. 2016), our results indicate that males in the “escalating smokers” group demonstrated significantly lower levels of internalizing problems than those in the “nonsmokers” group. It may be that cigarette use is a coping mechanism used by males to deal with symptoms of internalizing problems given the notion that cigarette smoking could facilitate alleviation of negative effects (Dahne et al. 2015) and the belief that cigarette smoking serves as an effective form of stress management (O’Callaghan and Doyle 2001). In fact, evidence has shown that males are more likely to cope with negativity by using external avoidance-based coping strategies, such as cigarette

smoking, whereas females are more prone to cope with negativity by using strategies like rumination (Nolen-Hoeksema and Corte 2003). Long-term follow-up is necessary to determine whether the observed relationship persists beyond young adulthood, and intervention programs may need to give greater consideration to providing adolescents with alternative strategies for treating internalizing problems.

This study had some limitations. First, our measure of sleep duration was based on adolescents’ self-reported data regarding time spent in bed, which may have slightly overestimated the true sleep duration because it includes the time taken to fall asleep and any time spent awake in bed during the night. The addition of sleep assessment with objective method, such as actigraphy and polysomnography, may provide more accurate calculation of sleep duration. Second, the measurement instruments used in our study were adapted from a number of existing scales to increase their applicability to adolescents in Taiwan; therefore, validity data were not available and the internal reliability was not high. The self-reported measures of sleep duration, cigarette smoking, and internalizing problems may also produce common method variance that may increase or decrease the association being examined. In addition, there is no consensus regarding the definitions of short and long sleep durations for adolescents with different cultural backgrounds. Interpretations of trajectory may change according to different social and cultural contexts. Furthermore, our study design could not infer causality between sleep duration and cigarette smoking or their relations with internalizing problems later. Finally, the study sample was recruited from schools in northern Taiwan and these participants generally reported low levels of internalizing problems. Therefore, caution should be used when generalizing the findings to other populations with different characteristics.

Nonetheless, the current study had several strengths. The use of group-based dual trajectory modeling enabled us to not only identify distinct trajectories of sleep duration and cigarette smoking, respectively, but also provide insights regarding inter-relationships among different trajectories of two outcomes. Additionally, examinations of the links between trajectories and subsequent internalizing problems helped to enhance the current understanding of different risks of developmental patterns of sleep duration and cigarette smoking. Our adjustments of important covariates when modeling inter-relationships for trajectories as well as relations with future internalizing outcomes further strengthened our study results. In addition, multiple imputation techniques were applied in the current study to reduce potential bias due to attrition.

In conclusion, our study provides important and novel insight into the nature of sleep duration and cigarette smoking, their inter-relationships, and their implications for mental health. The current findings highlight the significant relationships between sleep duration and cigarette smoking trajectories during adolescence, revealing that both “short declining”

and “long sleep” duration trajectories conferred increased risk of cigarette smoking. The findings indicate a need for integrated intervention efforts aimed at simultaneously adjusting sleep duration and diminishing cigarette smoking because these two constructs likely evolve together and/or are influenced by a similar third variable (e.g., shared internal liability). Our findings further underscore the importance of separately examining the impact of sleep duration and cigarette smoking on internalizing problems for males and females. Given that the effects of sleep duration and cigarette smoking on internalizing problems varied by sex and patterns of trajectories, tailored interventions may yield additional benefits regarding improving internalizing problems.

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### Compliance with Ethical Standards

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**Conflict of Interest** The authors declare that they have no conflict of interest.

**Ethical Approval** All procedures performed during studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

**Informed Consent** Informed consent was obtained from all child’s parent or guardian at baseline.

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