Nutr Res Pract. 2025 Apr;19(2):292-304
https://doi.org/10.4162/nrp.2025.19.2.292
pISSN 1976-1457·eISSN 2005-6168

Nutrition Research and Practice

Original Research

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Association between sleep timing shifts and dietary quality in Korean high school girls during COVID-19: a cross-sectional study

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OPEN ACCESS

Received: Oct 18, 2024
Revised: Jan 31, 2025
Accepted: Feb 8, 2025
Published online: Mar 24, 2025

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Conflict of Interest
The authors declare no potential conflicts of interests.

Author Contributions
Conceptualization: Kim MH, Kim E; Formal analysis: Kim MH, Jung Y, Kim E; Investigation: Kim MH; Methodology: Kim MH; Supervision:

ABSTRACT

BACKGROUND/OBJECTIVES: Owing to coronavirus disease 2019 (COVID-19), the shift from offline to online classes has caused significant changes in high school students' daily habits, including sleep patterns and dietary intake. This study explored the association between sleep schedule fluctuations and dietary quality among high school girls during the COVID-19 pandemic. This study examined the association between bedtime, wake-up time, and adolescent dietary quality during the weekly online/offline school period among 517 high school girls in Incheon, South Korea.
SUBJECTS/METHODS: The participants were divided into 2 groups: normal sleepers (n = 244), who maintained normal sleep schedules defined as a midpoint between bedtime and wake-up time before 5:30 a.m., during in-person and online classes; and late sleepers (n = 273), who maintained a normal sleep schedule during in-person classes but exhibited late sleep patterns defined as a midpoint after 5:30 a.m., during online classes.
RESULTS: Shorter sleep duration was characteristic of late sleepers with circadian rhythm disruption, who also displayed poorer dietary quality, including higher consumption of caffeinated beverages and street food and never consuming breakfast. Among the 5 constituent factors, disrupted sleep timing was associated with lower Nutrition Quotient for Adolescents scores in total, moderation, and environment. This association persisted independent of the grade level, even after adjusting for school grade. These findings highlight the significant effect of sleep patterns on dietary habits.
CONCLUSION: This study highlights the significant relationship between disrupted circadian rhythms and poor dietary quality among high-school girls. These findings reveal the need for interventions to promote healthy sleep patterns as a strategy to improve the dietary quality and overall health of adolescents.

Keywords: Sleep latency; COVID-19; circadian rhythm; nutritional quality

INTRODUCTION

Sleep is a natural, reversible state primarily controlled by neurobiological processes and a crucial physiological function for maintaining health and well-being [1,2]. Sleep duration varies significantly across populations and is influenced by both biological and social factors.

Kim E; Writing - original draft: Kim MH, Jung Y, Kim E; Writing - review & editing: Kim MH, Kim E.

Sleep timing and length are controlled by the interaction between the circadian clock and homeostatic sleep pressure [3]. The timing of the sleep-wake cycle can influence health, weight management, and metabolism, particularly when it conflicts with social or work demands. For example, the mismatch between internal rhythms and sleep-wake cycle shifts forces workers to carry out their tasks and sleep at biologically incorrect times, which can increase the chance of developing various medical problems, including metabolic syndrome, affecting physical and mental health [4]. Sleep-timing shifts can result in reduced sleep duration or misalignment between circadian rhythms and dietary intake. Several studies have shown that people who sleep later report shorter sleep durations, especially on weekdays and longer sleep durations on weekends [5,6]. Altered sleep timing can also cause circadian disturbances, which can independently influence biological processes and behaviors [7,8].

The coronavirus disease 2019 (COVID-19) pandemic has caused psychological stress and anxiety and has disrupted the daily routines of many individuals for various reasons, including stay-at-home orders and school campus disruptions [9-11]. In the early days of the COVID-19 outbreak, school classes were closed or replaced by online classes in many countries, and for some time [12], South Korea also ran online and in-person classes on a bi-weekly or every 2 weeks basis to reduce student crowding, as it transitioned from fully online classes early in the pandemic to gradually returning to in-person classes. During in-person classes, students are often forced to wake up in the early morning hours because of school hour restrictions, whereas online classes allow students to set their sleep times according to their sleep rhythms. During the pandemic, over half of the participants went to bed and woke up later, with more than one-third experiencing increased sleep disturbances [13]. Shifts in sleep timing can affect circadian rhythms, including sleep duration and quality, which may affect eating behavior and diet quality. In the early phase of the pandemic, younger adults, lower-income individuals, racial and ethnic minorities, and obese people increased their consumption of sugary foods and beverages [14]. Decreased physical activity, weight gain, irregular eating habits, and increased consumption of processed foods, delivery foods, and snacks were observed during the COVID-19 outbreak among female college students [15]. It seems plausible that these changes in circadian rhythms, including sleep timing, during the pandemic are linked to changes in dietary habits. However, research examining the association between shifts in sleep timing and students' eating behaviors and dietary quality in response to changes in schooling modalities during the COVID-19 pandemic is lacking. Therefore, this study aimed to investigate the relationship between alterations in sleep timing due to modifications in class formats during the COVID-19 pandemic and dietary quality among high school girls in South Korea. We examined the association between changes in sleep timing shifts and dietary quality in these students during the COVID-19 period.

SUBJECTS AND METHODS

Study participants

This study was conducted among healthy high-school girls residing in Incheon, South Korea. Participants were recruited through convenience sampling from 2 different general girls' high schools located in different districts of Incheon, which agreed to participate in the survey. The purpose and methodology of the survey were fully explained to the students, and parental consent to complete the questionnaire was obtained and submitted by students who understood it fully. Those who agreed to participate in the survey were given a questionnaire and asked to answer it directly. A total of 600 questionnaires were distributed, of which 517

were used for the final analysis after excluding those that were not returned or answered in an unreliable manner. This study was approved by the Institutional Review Board of Kongju National University (KNU_IRB_2021-21). Written informed consent was obtained from all participants and all procedures were performed according to the research ethics regulations and guidelines.

Survey on general characteristics and lifestyles

Participants completed a self-administered questionnaire survey. The questionnaire consisted of questions related to participants' general characteristics and lifestyles. General characteristics and lifestyles included school grade, wake-up time and bedtime for in-person classes, wake-up time and bedtime for online classes, exercise frequency, height, and weight. Body mass index (BMI) was determined by dividing the weight (kg) by height squared (m^2).

Sleep timing

A previous study [16] categorized participants into sleep time groups based on the median time between bedtime and wake-up time. Sleep duration was calculated based on the reported bedtime and wake-up time through questions such as "What time do you go to bed during in-person/online classes?" and "What time do you wake up during in-person/online classes?". Participants were categorized as normal sleepers if the midpoint between bedtime and waking up was before 5:30 a.m., which is also the 50th percentile of sleep time in the subjects, and as late sleepers if it was after 5:30 a.m. The participants were divided into 2 groups: normal sleepers (n = 244), who maintained normal sleep schedules during in-person and online classes; and late sleepers (n = 273), who maintained a normal sleep schedule during in-person classes but exhibited late sleep patterns during online classes.

Evaluation of dietary quality via the nutrition quotient for Korean adults

The dietary quality of the participants was assessed using the Nutritional Quotient for Korean Adolescents (NQ-A) developed by the Korean Nutrition Society [17]. The NQ-A consists of 19 items that assess 5 factors: balance, diversity, moderation, environment, and practice. The balance factor comprised 4 questions on fruit, white milk, beans, or bean products, and fish intake frequency. The diversity factor comprised 3 questions on the number of vegetable dishes, diverse side dishes, and refusal of specific food items. The moderation factor consisted of 6 questions about the intake frequency of cookies, sweet and greasy bread, processed beverages, instant noodles, caffeinated beverages, nighttime snacks, and street food. Environmental factors consisted of 3 questions about breakfast intake frequency, not moving around while eating, and screen time. The practice factor consisted of 3 questions: checking nutritional fact labels, washing hands before meals, and frequency of exercise. Based on the participants' responses to the 19 questions, the NQ-A score and the score for each area were calculated out of 100 points after multiplying the score calculated for each evaluation item by the weight and adding them all together [17]. The calculated NQ-A score assessed the dietary quality of the participants, with higher values indicating better dietary quality. In [17], the discrimination criteria for NQ-A scores were based on standardized percentile distributions from a nationwide survey.

Statistical analysis

Statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). Frequencies, means, and standard deviations were calculated for all variables. Differences in variables according to the sleep timing group were verified via the χ^2-test for noncontinuous variables and via the unpaired *t*-test for continuous variables. Logistic regression models

https://doi.org/10.4162/nrp.2025.19.2.292

were used to examine the associations between various factors and shifts in sleep timing. Since school grade was significantly associated with sleep timing, a grade-adjusted logistic regression analysis was performed. Analysis of covariance (ANCOVA) was conducted to calculate the adjusted means of the NQ-A and its constituent factors by grade, and the least squares means and SE were estimated. Statistical significance was set at $P < 0.05$ level.

RESULTS

General characteristics and lifestyle behaviors

The general characteristics and lifestyle behaviors of the participants are presented in **Table 1**. For the normal sleepers, 41.8% of 10th, 32.0% of 11th, and 26.2% of 12th, while for the late sleepers, 27.5% of 10th, 35.2% of 11th, and 37.3% of 12th a significant difference was observed ($P < 0.01$). The proportion of normal sleepers was lower in grade 10th to grade 12th, while the

Table 1. General characteristics and lifestyles of the high school girls

Variables	Criteria	Total (n = 517)	Normal sleeper (n = 244)	Late sleeper (n = 273)	χ^2 (*t*)-value (*P*-value)
Grade	10th	177 (34.2)	102 (41.8)	75 (27.5)	13.0940 (0.0014)
	11th	174 (33.7)	78 (32.0)	96 (35.2)	
	12th	166 (32.1)	64 (26.2)	102 (37.3)	
BMI (kg/m^2)	< 18.5	103 (19.9)	45 (18.5)	58 (21.2)	2.8012 (0.4233)
	≥ 18.5, < 23	317 (61.3)	154 (63.1)	163 (59.7)	
	≥ 23, < 25	57 (11.0)	23 (9.4)	34 (12.5)	
	≥ 25	40 (7.8)	22 (9.0)	18 (6.6)	
	Mean BMI	20.7 ± 2.8	20.8 ± 2.8	20.6 ± 2.8	0.63 (0.5275)
Wake up time when going to school	Before 7:00 a.m.	111 (21.5)	62 (25.4)	49 (17.9)	4.8330 (0.1844)
	7:00 a.m.–before 7:30 a.m.	251 (48.5)	112 (45.9)	139 (50.9)	
	7:30 a.m.–before 8:00 a.m.	152 (29.4)	68 (27.9)	84 (30.8)	
	After 8:00 a.m.	3 (0.6)	2 (0.8)	1 (0.4)	
Wake up time when online class	Before 7:00 a.m.	12 (2.3)	12 (5.0)	0 (0.0)	58.4990 (< 0.0001)
	7:00 a.m.–before 7:30 a.m.	10 (1.9)	10 (4.1)	0 (0.0)	
	7:30 a.m.–before 8:00 a.m.	35 (6.8)	32 (13.1)	3 (1.1)	
	After 8:00 a.m.	460 (88.9)	190 (77.8)	270 (98.9)	
Bedtime when going to school	Before 12:00 a.m.	27 (5.2)	23 (9.4)	4 (1.5)	203.6289 (< 0.0001)
	12:00 a.m.–before 1:00 a.m.	119 (23.0)	100 (41.0)	19 (6.9)	
	1:00 a.m.–before 2:00 a.m.	175 (33.9)	103 (42.2)	72 (26.4)	
	2:00 a.m.–before 3:00 a.m.	161 (31.1)	15 (6.2)	146 (53.5)	
	After 3:00 a.m.	35 (6.8)	3 (1.2)	32 (11.7)	
Bedtime during online class	Before 12:00 a.m.	17 (3.3)	17 (7.0)	0 (0.0)	460.8487 (< 0.0001)
	12:00 a.m.–before 1:00 a.m.	75 (14.5)	75 (30.7)	0 (0.0)	
	1:00 a.m.–before 2:00 a.m.	137 (26.5)	137 (56.2)	0 (0.0)	
	2:00 a.m.–before 3:00 a.m.	174 (33.7)	13 (5.3)	161 (59.0)	
	After 3:00 a.m.	114 (22.0)	2 (0.8)	112 (41.0)	
Sleep duration when going to school (h)	< 5	137 (26.50)	16 (6.56)	121 (44.32)	146.09 (< 0.0001)
	≥ 5, < 6	193 (37.33)	81 (33.20)	112 (41.03)	
	≥ 6, < 7	124 (23.98)	95 (38.93)	29 (10.62)	
	≥ 7	63 (12.19)	52 (21.31)	11 (4.03)	
	Mean duration	5.7 ± 1.1	6.2 ± 0.9	5.1 ± 0.9	13.91 (< 0.0001)
Sleep duration when online class (h)	< 5	9 (1.81)	6 (2.50)	3 (1.17)	392.126 (< 0.0001)
	≥ 5, < 6	116 (23.34)	15 (6.25)	101 (39.30)	
	≥ 6, < 7	165 (33.20)	12 (5.00)	153 (59.53)	
	≥ 7	207 (41.65)	207 (86.25)	0 (0.00)	
	Mean duration	6.3 ± 1.1	7.1 ± 0.9	5.6 ± 0.5	24.13 (< 0.0001)

Values are presented as number (%) or mean ± SD.
Normal sleeper: Participants who maintained a consistent sleep schedule, with the midpoint between bedtime and wake-up time occurring before 5:30 a.m., during both in-person and online classes. Late sleeper: Participants who maintained a normal sleep schedule during in-person classes but adopted a late sleep pattern during online classes, with the midpoint occurring after 5:30 a.m.

https://doi.org/10.4162/nrp.2025.19.2.292

proportion of late sleepers was higher from grade 10th to grade 12th. Mean height, weight, and BMI were not significantly different between normal and late sleepers. During the offline class period, wake-up times did not differ significantly between the normal and late sleeper groups, with most students waking up before 8:00 a.m. In contrast, a significant shift was observed during the online class period, as 98.9% of late sleepers woke up after 8:00 a.m., compared to 77.8% of normal sleepers ($P < 0.0001$). Regarding bedtime during the offline class period, 9.4% of normal sleepers went to bed before midnight, whereas only 1.5% of late sleepers did so. Notably, 92.6% of the normal sleepers went to bed before 2:00 a.m., whereas 65.2% of the late sleepers went to bed after 2:00 a.m. ($P < 0.0001$). This difference became even more pronounced during the online class period, where only 6.1% of normal sleepers went to bed after 2:00 a.m., compared to 100% of late sleepers ($P < 0.0001$). Consequently, during the online class period, the sleep duration of late sleepers averaged 5.6 h, which was significantly shorter than the 7.1 h averaged by normal sleepers ($P < 0.0001$).

Dietary behaviors

Tables 2-5 shows participants' dietary behaviors across five constituent factors used to evaluate NQ-A and their association with being a late sleeper. The results on the dietary behaviors related to dietary balance are presented in **Table 2**. No significant differences were noted in the frequency of consumption of fruits, white milk, beans, bean products, or fish between the 2 groups based on sleep timing. The results on the dietary behaviors related to dietary moderation are shown in **Table 3**. The frequency of caffeinated beverage consumption was significantly higher in late sleepers than in normal sleepers ($P < 0.05$). No significant differences were observed in the frequency of instant noodles, sweet and greasy bread, processed beverages, late-night snacks, or street food consumption between the 2 groups. In the logistic regression models, even after adjusting for school grade, consuming caffeinated

Table 2. Participants' dietary behaviors related to dietary balance and their association with sleep pattern classification

Variables	Criteria	Total (n = 517)	Normal sleeper (n = 244)	Late sleeper (n = 273)	χ^2-value (*P*-value)	AOR	95% CI
Intake frequency of fruit	≥ 2 times a day	37 (7.2)	20 (8.2)	17 (6.2)	2.6626 (0.6158)	Reference	
	Once a day	104 (20.1)	49 (20.1)	55 (20.2)		1.126	0.522–2.429
	3–4 times per week	195 (37.7)	92 (37.7)	103 (37.7)		1.134	0.553–2.326
	Once per week	117 (22.6)	58 (23.8)	59 (21.6)		1.053	0.495–2.239
	Never	64 (12.4)	25 (10.2)	39 (14.3)		1.705	0.744–3.903
Intake frequency of white milk	≥ Once a day	54 (10.5)	23 (9.4)	31 (11.4)	1.5509 (0.6706)	Reference	
	3–4 times per week	134 (25.9)	61 (25.0)	73 (26.7)		0.908	0.476–1.733
	Once per week	108 (20.9)	56 (23.0)	52 (19.0)		0.681	0.349–1.330
	Never	221 (42.7)	104 (42.6)	117 (42.9)		0.871	0.473–1.605
Intake frequency of bean or bean product	≥ 3–4 times per week	139 (26.7)	72 (29.5)	67 (24.5)	2.193 (0.7065)	Reference	
	Once per week	151 (29.2)	71 (29.1)	80 (29.3)		1.181	0.740–2.655
	Once every 2 weeks	76 (14.7)	32 (13.1)	44 (16.1)		1.499	0.846–2.655
	Once per month	62 (12.0)	29 (11.9)	33 (12.1)		1.155	0.629–2.213
	Never	89 (17.2)	40 (16.4)	49 (18.0)		1.281	0.745–2.201
Intake frequency of fish	≥ 3 times per week	25 (4.8)	14 (5.8)	11 (4.0)	2.7765 (0.5959)	Reference	
	Once per week	123 (23.8)	51 (20.9)	72 (26.4)		1.824	0.756–4.398
	Once every 2 weeks	122 (23.6)	60 (24.6)	62 (22.7)		1.314	0.546–3.159
	Once per month	158 (30.6)	75 (30.7)	83 (30.4)		1.413	0.598–3.341
	Never	89 (17.2)	44 (18.0)	45 (16.5)		1.201	0.486–2.969

Values are presented as number (%).
AORs with 95% CI of being a late sleeper were estimated using logistic regression, adjusting for school grade.
Normal sleeper: Participants who maintained a consistent sleep schedule, with the midpoint between bedtime and wake-up time occurring before 5:30 a.m., during both in-person and online classes. Late sleeper: Participants who maintained a normal sleep schedule during in-person classes but adopted a late sleep pattern during online classes, with the midpoint occurring after 5:30 a.m.
AOR, adjusted odds ratio; CI, confidence interval.

https://doi.org/10.4162/nrp.2025.19.2.292

Table 3. Participants' dietary behaviors related to dietary moderation and their association with sleep pattern classification

Variables	Criteria	Total (n = 517)	Normal sleeper (n = 244)	Late sleeper (n = 273)	χ^2-value (*P*-value)	AOR	95% CI
Intake frequency of instant noodles	≥ 3 times per week	110 (21.3)	47 (19.3)	63 (23.1)	2.6794 (0.4437)	1.693	0.933–3.017
	Once per week	216 (41.8)	99 (40.6)	117 (42.8)		1.422	0.837–2.416
	Once every 2 weeks	113 (21.8)	56 (22.9)	57 (20.9)		1.200	0.666–2.161
	≤ Once per month	78 (15.1)	42 (17.2)	36 (13.2)		Reference	
Intake frequency of cookies or sweet and greasy bread	≥ 2 times a day	80 (15.5)	38 (15.6)	42 (15.4)	5.0997 (0.1646)	1.295	0.667–2.513
	Once a day	241 (46.6)	102 (41.8)	139 (50.9)		1.520	0.876–2.644
	3–4 times a per week	130 (25.2)	70 (28.7)	60 (22.0)		0.979	0.536–1.787
	≤ Once per month	66 (12.7)	34 (13.9)	32 (11.7)		Reference	
Intake frequency of processed beverage	≥ Once a day	111 (21.5)	53 (21.7)	58 (21.2)	5.9252 (0.2048)	1.440	0.721–2.875
	3–4 times per week	208 (40.2)	86 (35.2)	122 (44.7)		1.813	0.954–3.446
	Once per week	110 (21.3)	58 (23.8)	52 (19.1)		1.163	0.583–2.323
	Once every 2 weeks	40 (7.7)	20 (8.2)	20 (7.3)		1.153	0.491–2.709
	≤ Once per month	48 (9.3)	27 (11.1)	21 (7.7)		Reference	
Intake frequency of caffeinated beverage	≥ Once a day	51 (9.86)	20 (8.20)	31 (11.36)	7.8645 (0.1639)	1.775	0.919–3.456
	3–4 times per week	112 (21.66)	44 (18.03)	68 (24.91)		1.866	**1.112–3.132**
	Once per week	87 (16.83)	41 (16.80)	46 (16.85)		1.314	0.757–2.280
	Once every 2 weeks	43 (8.32)	22 (9.02)	21 (7.69)		1.227	0.610–2.467
	Once per month	90 (17.41)	43 (17.62)	47 (17.22)		1.299	0.754–2.237
	Never	134 (25.92)	74 (30.33)	60 (21.98)		Reference	
Intake frequency of night time snack	≥ 3 times per week	118 (22.8)	45 (18.5)	73 (26.7)	5.1031 (0.1644)	1.723	**1.056–2.811**
	Once per week	127 (24.6)	63 (25.8)	64 (23.4)		0.997	0.624–1.593
	Once every 2 weeks	106 (20.5)	54 (22.1)	52 (19.1)		0.977	0.595–1.603
	Never	166 (32.1)	82 (33.6)	84 (30.8)		Reference	
Intake frequency of street food	≥ 3 times per week	191 (36.9)	83 (34.0)	108 (39.6)	4.6325 (0.2008)	2.048	**1.107–3.790**
	Once per week	160 (31.0)	76 (31.2)	84 (30.8)		1.743	0.929–3.271
	Once every 2 weeks	109 (21.1)	51 (20.9)	58 (21.2)		1.698	0.873–3.305
	Never	57 (11.0)	34 (13.9)	23 (8.4)		Reference	

Values are presented as number (%).
AORs with 95% CI of being a late sleeper were estimated using logistic regression, adjusting for school grade.
Bold values indicate statistical significance, where the 95% CI does not include 1.
Normal sleeper: Participants who maintained a consistent sleep schedule, with the midpoint between bedtime and wake-up time occurring before 5:30 a.m., during both in-person and online classes. Late sleeper: Participants who maintained a normal sleep schedule during in-person classes but adopted a late sleep pattern during online classes, with the midpoint occurring after 5:30 a.m.
AOR, adjusted odds ratio; CI, confidence interval.

Table 4. Participants' dietary behaviors related to dietary diversity and their association with sleep pattern classification

Variables	Criteria	Total (n = 517)	Normal sleeper (n = 244)	Late sleeper (n = 273)	χ^2-value (*P*-value)	AOR	95% CI
Number of vegetable dishes	≥ 4	81 (15.7)	37 (15.2)	44 (16.1)	0.5844 (0.9000)	Reference	
	3	185 (35.8)	90 (36.9)	95 (34.8)		0.905	0.531–1.541
	2	178 (34.4)	85 (34.8)	93 (34.1)		0.964	0.565–1.647
	≤ 1	73 (14.1)	32 (13.1)	41 (15.0)		1.151	0.602–2.202
Diverse side dishes	Always	98 (18.9)	44 (18.0)	54 (19.8)	2.43 (0.5043)	Reference	
	Often	171 (33.1)	87 (35.7)	84 (30.8)		0.840	0.507–1.394
	Moderate	170 (32.9)	81 (33.2)	89 (32.6)		1.005	0.604–1.673
	Seldom or never	78 (15.1)	32 (13.1)	46 (16.8)		1.296	0.703–2.391
Refusal of specific food items	A lot	39 (7.5)	17 (7.0)	22 (8.1)	4.6879 (0.3208)	1.800	0.721–4.493
	Frequently	123 (23.8)	50 (20.5)	73 (26.7)		2.141	**1.013–4.525**
	Moderate	219 (42.4)	105 (43.0)	114 (41.7)		1.490	0.735–3.018
	Seldom	98 (19.0)	50 (20.5)	48 (17.6)		1.274	0.591–2.746
	Never	38 (7.3)	22 (9.0)	16 (5.9)		Reference	

Values are presented as number (%).
AORs with 95% CI of being a late sleeper were estimated using logistic regression, adjusting for school grade.
Bold values indicate statistical significance, where the 95% CI does not include 1.
Normal sleeper: Participants who maintained a consistent sleep schedule, with the midpoint between bedtime and wake-up time occurring before 5:30 a.m., during both in-person and online classes. Late sleeper: Participants who maintained a normal sleep schedule during in-person classes but adopted a late sleep pattern during online classes, with the midpoint occurring after 5:30 a.m.
AOR, adjusted odds ratio; CI, confidence interval.

https://doi.org/10.4162/nrp.2025.19.2.292

Table 5. Participants' dietary behaviors related to dietary practice and environment and their association with sleep pattern classification

Variables	Criteria	Total (n = 517)	Normal sleeper (n = 244)	Late sleeper (n = 273)	χ^2-value (*P*-value)	AOR	95% CI
Practice							
Check nutrition fact labelling	Often or always	108 (20.9)	55 (22.5)	53 (19.4)	1.3028 (0.7285)	Reference	
	Moderate	236 (45.6)	111 (45.5)	125 (45.8)		1.111	0.700–1.735
	Seldom	113 (21.9)	49 (20.1)	64 (23.4)		1.367	0.798–2.342
	Never	60 (11.6)	29 (11.9)	31 (11.4)		1.128	0.594–2.214
Wash hands before meals	Always	140 (27.1)	72 (29.5)	68 (24.9)	1.5906 (0.6615)	Reference	
	Often	215 (41.6)	99 (40.6)	116 (42.5)		1.226	0.796–1.888
	Moderate	124 (24.0)	57 (23.4)	67 (24.5)		1.181	0.722–1.930
	Seldom or never	38 (7.3)	16 (6.5)	22 (8.1)		1.603	0.767–3.351
Frequency of exercise	≥ 5 times per week	77 (14.9)	36 (14.8)	41 (15.1)	9.8932 (0.0195)	Reference	
	3–4 times per week	143 (27.6)	79 (32.4)	64 (23.4)		0.771	0.438–1.355
	1–2 times per week	199 (38.5)	95 (38.9)	104 (38.1)		0.967	0.567–1.648
	Never	98 (19.0)	34 (13.9)	64 (23.4)		1.727	0.930–3.207
Environment							
Intake frequency of breakfast	Everyday	204 (39.5)	103 (42.2)	101 (37.0)	7.0391 (0.1338)	Reference	
	5–6 times per week	101 (19.5)	54 (22.1)	47 (17.2)		0.888	0.547–1.441
	3–4 times per week	42 (8.1)	19 (7.8)	23 (8.4)		1.282	0.652–2.523
	1–2 times per week	29 (5.6)	14 (5.8)	15 (5.5)		1.003	0.455–2.209
	Never	141 (27.3)	54 (22.1)	87 (31.9)		1.694	**1.087–2.639**
Not moving around while eating	Always	302 (58.4)	146 (59.8)	156 (57.1)	1.7316 (0.6299)	Reference	
	Often	157 (30.4)	72 (29.5)	85 (31.2)		1.127	0.761–1.668
	Moderate	45 (8.7)	22 (9.1)	23 (8.4)		1.088	0.575–2.060
	Seldom or never	13 (2.5)	4 (1.6)	9 (3.3)		2.535	0.752–8.540
Screen time (h/day)	≥ 4	244 (47.2)	116 (47.5)	128 (46.9)	6.4976 (0.0898)	0.801	0.404–1.591
	3	188 (36.4)	97 (39.8)	91 (33.3)		0.71	0.352–1.429
	2	45 (8.7)	14 (5.7)	31 (11.4)		1.578	0.641–3.888
	1	40 (7.7)	17 (7.0)	23 (8.4)		Reference	

Values are presented as number (%).
AORs with 95% CI of being a late sleeper were estimated using logistic regression, adjusting for school grade.
Bold values indicate statistical significance, where the 95% CI does not include 1.
Normal sleeper: Participants who maintained a consistent sleep schedule, with the midpoint between bedtime and wake-up time occurring before 5:30 a.m., during both in-person and online classes. Late sleeper: Participants who maintained a normal sleep schedule during in-person classes but adopted a late sleep pattern during online classes, with the midpoint occurring after 5:30 a.m.
AOR, adjusted odds ratio; CI, confidence interval.

beverages 3–4 times per week increased the odds by 1.866 (95% confidence interval [CI], 1.112–2.132). Similarly, eating late-night snacks three or more times per week increased the odds by 1.723 times (95% CI, 1.056–2.811), and consuming street food three or more times per week increased the odds by 2.048 times (95% CI, 1.107–3.790), compared to those who did not consume these items. The results on the dietary behaviors related to dietary diversity are presented in **Table 4**. No differences were noted between the groups in the number of vegetable side dishes per meal, the variety of side dishes consumed, or picky eating. The results on the dietary behaviors related to dietary practice and environment are displayed in **Table 5**. Dietary behaviors assessing the practice areas of eating did not differ between the 2 groups for reading nutrition labels and hand washing; however, for exercise frequency, the proportion of those who exercised three or more times per week was higher in normal sleepers than in late sleepers (47.2% and 38.5%, respectively; $P < 0.05$). Dietary behavior questions related to the environmental areas of eating did not show any significant differences between the 2 groups in terms of the frequency of breakfast consumption, not moving around while eating, or time spent on TV and smart devices. Additionally, in the logistic regression models, after adjusting for school grade, skipping breakfast daily was associated with 1.694 times (95% CI, 1.087–2.639) increased likelihood of late sleepers compared to regularly eating breakfast. Although exercise frequency differed significantly between the 2 groups, no significant association was seen in the grade-adjusted logistic regression models.

https://doi.org/10.4162/nrp.2025.19.2.292

Dietary quality

Table 6 shows the dietary quality assessed using participants' NQ-A scores. The NQ-A score assessing the quality of adolescent meals was 50.1 for the normal sleepers, significantly higher than 47.4 for the late sleepers ($P < 0.01$). Among the 5 constituent factors assessed, the moderation and environment areas were significantly higher ($P < 0.01$, $P < 0.05$) in normal sleepers with scores of 48.0 and 66.5, respectively, than in late sleepers with scores of 43.6 and 62.7, respectively. No significant differences were seen between the 2 groups in terms of balance, diversity, and practice area. As shown in **Table 3** and **Fig. 1**, the grade-adjusted means,

Table 6. NQ for Korean adolescents score and sub-domain score of the high school girls according to the sleep pattern classification

Variables	Level	Total (n = 517)	Normal sleeper (n = 244)	Late sleeper (n = 273)	$\chi^2(t)$-value (*P*-value)	AOR	95% CI
NQ	High/moderate	242 (46.81)	123 (50.41)	119 (43.59)	2.4070 (0.1208)	Reference	
	Low	275 (53.19)	121 (49.59)	154 (56.41)		1.391	0.976–1.983
	Mean score	48.7 ± 10.0	50.1 ± 9.7	47.4 ± 10.0	3.05 (0.0024)		
Balance	High/moderate	171 (33.08)	82 (33.61)	89 (32.60)	0.0589 (0.8083)	Reference	
	Low	346 (66.92)	162 (66.39)	184 (67.40)		0.987	0.680–14343
	Mean score	39.3 ± 17.9	39.8 ± 17.3	38.9 ± 18.5	0.57 (0.5669)		
Moderation	High/moderate	360 (69.63)	182 (74.59)	178 (62.50)	5.3710 (0.0205)	Reference	
	Low	157 (30.37)	62 (25.41)	95 (34.80)		1.590	**1.080–2.341**
	Mean score	45.7 ± 16.1	48.0 ± 16.2	43.6 ± 15.7	3.11 (0.0019)		
Diversity	High/moderate	326 (63.06)	162 (66.39)	164 (60.07)	2.2093 (0.1372)	Reference	
	Low	191 (36.94)	82 (33.61)	109 (39.93)		1.393	0.966–2.009
	Mean score	50.5 ± 20.6	51.4 ± 19.8	49.8 ± 21.2	0.89 (0.3755)		
Practice	High/moderate	407 (78.72)	202 (82.79)	205 (75.09)	4.5552 (0.0328)	Reference	
	Low	110 (21.28)	42 (17.21)	68 (24.91)		1.668	**1.076–2.584**
	Mean score	50.8 ± 16.4	52.2 ± 15.7	49.6 ± 16.9	1.79 (0.0735)		
Environment	High/moderate	326 (63.06)	166 (68.03)	160 (58.61)	4.9128 (0.0267)	Reference	
	Low	191 (36.94)	78 (31.97)	113 (41.39)		1.546	**1.071–2.231**
	Mean score	64.5 ± 20.1	66.5 ± 19.1	62.7 ± 20.8	2.16 (0.0313)		

Values are presented as number (%) or mean ± SD.
AORs with 95% CI of being a late sleeper were estimated using logistic regression, adjusting for school grade.
Bold values indicate statistical significance, where the 95% CI does not include 1.
Normal sleeper: Participants who maintained a consistent sleep schedule, with the midpoint between bedtime and wake-up time occurring before 5:30 a.m., during both in-person and online classes. Late sleeper: Participants who maintained a normal sleep schedule during in-person classes but adopted a late sleep pattern during online classes, with the midpoint occurring after 5:30 a.m.
NQ, nutrition quotient; AOR, adjusted odds ratio; CI, confidence interval.

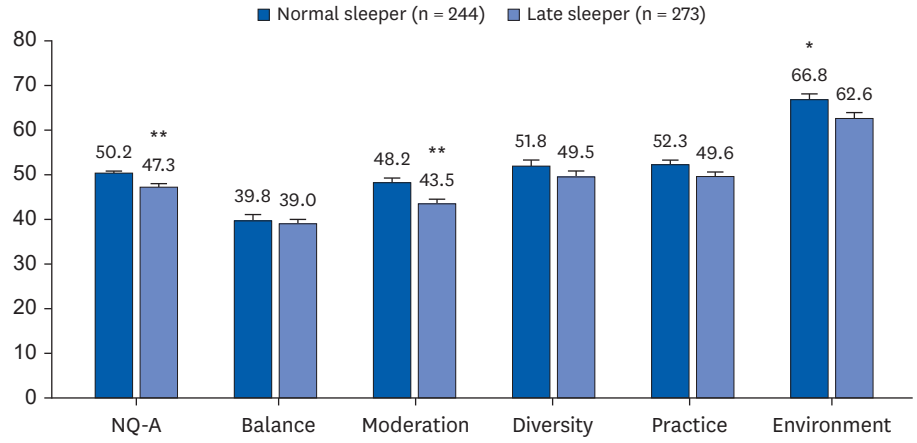

Fig. 1. School grade adjusted mean scores of NQ-A and constituent factors of the high school girls according to the sleep timing.
The height of the bars represents means adjusted for grade using analysis of covariance, and the error bars indicate the SEs.
Normal sleeper: Participants who maintained a consistent sleep schedule, with the midpoint between bedtime and wake-up time occurring before 5:30 a.m., during both in-person and online classes. Late sleeper: Participants who maintained a normal sleep schedule during in-person classes but adopted a late sleep pattern during online classes, with the midpoint occurring after 5:30 a.m.
NQ-A, nutrition quotient for Korean adolescents.
$^{*}P < 0.05$, $^{**}P < 0.01$.

https://doi.org/10.4162/nrp.2025.19.2.292

NQ-A ($P < 0.01$), moderation ($P < 0.01$), and environment scores ($P < 0.05$) were significantly lower in the late sleep group than in the normal sleep group. Furthermore, in grade-adjusted logistic regression models, those belonging to the lower category of moderation and practice factors were associated with 1.590 times (95% CI, 1.080–2.341) and 1.668 times (95% CI, 1.076–2.684) increased odds of being classified as late sleepers, respectively, compared to those in the middle or higher categories.

DISCUSSION

This study investigated the relationship between changes in sleep timing caused by modifications in school class formats (in-person/online classes) during the COVID-19 pandemic, and their impact on dietary quality among high school girls in South Korea. We specifically examined how alterations in sleep duration influenced the dietary habits of students during this period. Late sleepers with circadian rhythm disruption exhibited shorter sleep duration and poorer dietary quality, including higher consumption of caffeinated beverages, late-night snacks, and street food, as well as more frequent breakfast skipping. Among the 5 constituent factors, sleep timing disruptions were associated with lower total NQ-A scores, as well as moderation and environment.

Adolescence is a crucial developmental stage for both physical and psychological growth. Adolescents often have shorter sleep durations at night and experience delayed sleep-wake cycles compared to children [18,19]. These circadian rhythm shifts are caused by environmental and psychosocial factors such as early school start times and academic pressures, which can lead to a higher rate of insufficient sleep among adolescents [20,21]. The academic stress caused by college entrance examinations can raise mental and physical health issues [22,23]. This excessive stress not only diminishes their quality of life but can also lead to mental health issues and social problems [24]. Furthermore, individuals with a preference for eveningness (a later sleep-wake cycle) typically have more irregular sleep-wake schedules than those who prefer morningness (an earlier sleep-wake cycle) [25,26]. Adolescents generally show an age-related increase in eveningness, similar to the results of our study [27]. Furthermore, an analysis of American adolescents' sleep duration using data from Monitoring the Future revealed a trend of decreasing sleep duration as age increased from 12 to 18 yrs in the US [28]. According to the statistics from the 2023 Korea Youth Risk Behavior Survey conducted by the Korea Disease Control and Prevention Agency, the biggest sources of stress among middle and high school students in South Korea were academic performance and concerns about their future careers [29]. Research involving adolescents has also demonstrated a significant link between the preference for eveningness and various health issues, including depression, diabetes, and psychological, neurological, respiratory, and gastrointestinal/abdominal disorders [30,31]. In this study, a higher proportion of late sleepers was observed among students in higher grades. While there was no significant difference in wake-up times between normal sleepers and late sleepers during the period of offline classes, the shift to online classes—where the constraint of fixed school start times was relatively relaxed—appears to have contributed to a higher tendency for delayed sleep patterns in higher-grade students. This suggests that external cues associated with online learning during the COVID-19 pandemic may have had a more pronounced impact on students in higher grades who were experiencing heightened academic pressure related to college entrance. Given that sleep patterns differed by grade level, potential confounding effects were taken into account. Accordingly, adjusted odds ratios were calculated with grade

https://doi.org/10.4162/nrp.2025.19.2.292

level included as a covariate to assess whether the observed differences between normal sleepers and late sleepers in relation to eating behaviors and diet quality were attributable to variations in grade-level distribution. To further control for grade-related variation, grade-adjusted ANCOVA was employed in the analysis of the relationship between sleep timing fluctuations and diet quality score.

Sleep duration is linked to dietary habits, physical activity, and various other health-related behaviors [32]. In the present study, we found that the proportion of individuals who did not exercise at all during the week was higher among late sleepers, the group in which changes in sleep phase was observed. However, in grade-adjusted logistic regression models, no significant association was found between exercise frequency and late sleep duration. This suggests that differences in exercise frequency are more likely to be related to school grades than to sleep patterns. In addition, late sleepers had significantly shorter sleep duration than normal sleepers, regardless of class type. In grade-adjusted logistic regression analysis, shorter sleep duration was associated with increased odds of late sleep only during in-person classes, with no significant association during online classes. Several studies have shown that physical activity enhances sleep onset and quality, while insufficient fitness is linked to poor sleep in young adults [33,34]. Among adolescents aged 11-16, moderate-to-vigorous physical activity has been associated with improved sleep quality; however, girls have lower physical activity levels and poorer sleep quality than boys [35]. Furthermore, the role of exercise in modulating circadian rhythms has been investigated. When performed at the right time of day, exercise can adjust the internal circadian rhythm phase and help correct circadian mismatch [36,37]. This is particularly beneficial for people with a late chronotype because shifting their internal circadian rhythm forward may help align their internal clocks more closely with the external environment and common social routines [37]. In line with previous findings, our study observed that the proportion of participants who exercised 3 or more times per week was higher among normal sleepers than among late sleepers. However, after adjusting for grade levels, this association was not statistically significant. One possible explanation is that our study did not account for details, such as exercise intensity and duration, which may have influenced the results. Therefore, further research is required to clarify the relationship between exercise characteristics and sleep-phase stability, particularly in adolescents.

In terms of nutritional aspects, late sleepers consumed caffeinated beverages more frequently than normal sleepers did. Additionally, meal quality, as measured by the NQ-A score, was higher in normal sleepers (50.2) than in late sleepers (47.3), even after grade adjustment. Among the 5 subareas assessed, normal sleepers scored significantly higher in the moderation and environment areas and total scores. Nutrient intake and dietary composition can influence sleep quality and phase [38]. Approximately 80% of teenagers regularly consume caffeine, reflecting its prevalence in their daily routines [39,40]. Caffeine consumption may worsen sleep problems by disrupting sleep and circadian rhythms. In a previous 28-h double-blind randomized crossover study, the effect of caffeine on slow-wave sleep and delayed circadian timing in teenagers [41]. In addition, using data from the 2014 and 2015 Korea Youth Risk Behavior Web-based Surveys, this study found that short sleep duration (< 6 h) and poor sleep quality among adolescents were associated with higher consumption of unhealthy foods, such as soft drinks, fast food, instant noodles, and confectionaries, and lower consumption of healthy foods, such as fruits, vegetables, and milk [42]. In addition to previous studies, our grade-adjusted logistic regression models identified specific dietary behaviors as risk factors for delayed sleep. Consuming caffeinated beverages (3–4 times per week), late-night snacks (more than 3 times per week), or street

https://doi.org/10.4162/nrp.2025.19.2.292

food (more than 3 times per week) significantly increased the risk, with odds ratios of 1.866, 1.723, and 2.048, respectively, compared with those who did not consume these items at all. Daily skipping of breakfast increased the risk of late sleepers by 1.694 times compared to regularly eating breakfast. This suggests that the transition to online classes has a greater impact on sleep pattern changes in higher-grade students. However, regardless of grade level distribution, sleep patterns per se appear to influence dietary behavior.

Another study found that longer sleep duration was associated with higher total NQ-A scores, reflecting better dietary quality, which was linked to reduced screen time and increased exercise duration among high school students in South Korea [43]. Consistent with previous studies, the present study demonstrated that better sleep quality without phase shifts is associated with healthier dietary habits, as evidenced by higher NQ-A scores. In contrast, late sleepers who consume more caffeinated beverages exhibit poorer sleep quality, emphasizing improved sleep patterns and better overall dietary quality. Our study also found that late sleepers had significantly lower NQ-A, moderation, and environmental scores than normal sleepers did. Additionally, lower moderation and practice factor scores increased the likelihood of being classified as late sleepers.

This study investigated, the relationship between changes in sleep phase and dietary quality among South Korean high school female students, specifically in the context of online and offline alternating schooling, which is an area that has not been widely investigated, during the COVID-19 period. Additionally, the study highlights the association between sleep phase shifts and dietary quality based on factors like exercise and caffeine intake, which is closely linked to circadian rhythm regulation by contributing valuable evidence to this field. However, our study has some limitations; it included only female high school students, highlighting the need for future research to examine different genders and broader age groups to better understand these associations across the overall population. Another limitation of this study is the need for further research employing a longitudinal, randomized control design across diverse regions to better elucidate the fundamental relationship between sleep patterns and the NQ-A in adolescents. Despite these limitations, maintaining consistent sleep patterns remains essential for promoting dietary quality and healthy eating habits, especially among high school students who experience routine changes due to varying class formats and exam periods. This highlights the need for comprehensive educational programs that focus on sleep patterns and nutritional quality to support overall health and well-being.

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