

Association between the Timing of Seafood, EPA, DHA Consumption and Sleep Pattern: A Cross-Sectional Study

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Summary Seafood, which is rich in omega-3 fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), is reported to be associated with sleep. Animal studies have suggested that these fatty acids influence circadian clock system. People can be classified into morning, intermediate, and evening types based on their chronotype. Social jetlag, defined as the discrepancy in sleep schedule between workdays and free days, is more pronounced in individuals with an evening chronotype. However, the association between the timing of seafood and EPA and or DHA consumption and sleep phase in humans remains unclear. This cross-sectional study aimed to examine the relationship between seafood, EPA, and DHA intake at three different mealtimes and from snacks and sleep patterns among Japanese adults. Dietary and sleep data were collected from 5,975 adults aged 18–75. Generalized estimating equations were used to assess the associations between sleep patterns and seafood, EPA, and DHA intake at breakfast, lunch, dinner, and snack times—measured using a mobile food-logging application—taking chronotype and social jetlag into consideration. Higher total daily intake of seafood, EPA, and DHA was associated with a morning chronotype and less social jetlag. Intake at breakfast and lunch related to morningness and less social jetlag, with breakfast showing the strongest association. These findings suggest that both the quantity and timing of seafood, EPA, and DHA intake may be related to sleep patterns; however, causal relationships cannot be inferred due to the cross-sectional design.

Key Words chronotype, omega-3 fatty acids, seafood, sleep, social jetlag

Sleep is essential for maintaining physiological functions and mental health, including memory, immunity, emotion regulation, and metabolism (1, 2). Using questionnaires to assess individual sleep schedules, people can be broadly classified into the chronotypes of morningness (early) intermediate (middle) or eveningness (late). People with a morning chronotype prefer earlier sleep onset and offset times. Conversely, those with an evening chronotype prefer later sleep onset and offset times (3, 4). Together with chronotype, the concept of jetlag has also been introduced: On workdays, individuals often adhere to school, work, or other social obligations, compelling them to wake up or go to bed at times that may deviate from their natural sleep patterns. This is referred to as the social clock. By contrast, on free days, people tend to align their sleep with their natural biological clock. Thus, the misalignment between the social and biological clocks is described as social jetlag (5–8).

Individuals with an evening chronotype commonly experience greater social jetlag (3, 7). Social jetlag and

a late chronotype have been associated with insufficient sleep and unhealthy dietary habits (3, 5, 9). Furthermore, several studies have revealed that greater social jetlag is linked to a high risk of various negative health outcomes, including obesity, metabolic disease, cancer, and depressive symptoms (3, 5, 7, 10).

A survey conducted by the Organisation for Economic Co-operation and Development in 2021 indicated that the average duration of sleep of Japanese people was the shortest among the 33 countries surveyed (11). This trend of insufficient sleep is further supported by the 2023 National Health and Nutrition Survey in Japan, which revealed that—especially in men aged 30 to 59 y and women aged 40 to 69 y—38.5% of men and 43.6% of women sleep less than 6 h per day (12). Given the high prevalence of sleep loss and the population at risk of social jetlag, this situation has become a significant public health concern (5, 10). These statistics emphasize a potential public health challenge within Japan, highlighting the crucial importance of investigating sleep patterns in this population.

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Previous research has indicated that dietary patterns and specific nutrients are associated with sleep outcomes (13, 14). A Finnish population-based study reported that individuals with eveningness tended to adhere less to a healthy Nordic diet (15). A systematic review also highlighted those consuming healthy foods are generally associated with better sleep, whereas higher intake of processed and free-sugar-rich foods tend to be linked with poorer sleep characteristics (16). A cross-sectional study of middle-aged Japanese women showed that poor sleep quality was associated with a low intake of vegetables and fish, as well as a high consumption of energy drinks, sugar-sweetened beverages, and carbohydrates (17). The mechanisms linking dietary factors to sleep remain unclear, but they are believed to involve neuroendocrine regulation and neuroinflammatory processes. In addition to overall dietary patterns, specific food components may also influence sleep. For instance, two studies have reported that seafood or fish intake affects sleep (16, 18). Omega-3 polyunsaturated fatty acids (n-3 PUFAs), which are abundant in seafood, are recognized for their crucial contributions to brain health. Notably, docosahexaenoic acid (DHA) is a structural component of neuronal membranes and contributes to neurotransmission, while eicosapentaenoic acid (EPA) can regulate metabolic and immune responses by reducing the levels of pro-inflammatory cytokines (16). Although a previous study identified differences in macronutrient intake between individuals with morning and evening chronotypes, no studies have investigated the relationship between chronotype and the intake of seafood, DHA, or EPA—nutrients known to influence the expression of circadian clock genes in animal study (19).

By tradition, the Japanese diet is characterized by high consumption of fish and seafood. This high intake of marine products suggests that, compared to those of other countries, the Japanese population typically has a relatively high intake of n-3 PUFAs, including EPA and DHA (20, 21). Although previous studies have explored the association between consuming seafood or n-3 PUFAs and sleep quality, disorders, or duration, little is known about their relationship with chronotype and social jetlag (2, 13, 22, 23). Moreover, a significant gap in understanding exists regarding whether the timing of specific nutrient intake is related to sleep patterns. Most existing research has focused on total daily intake rather than the temporal distribution of nutrient intake (2, 13, 22, 23). Considering the distinct dietary habits and sleep status of the Japanese population, investigating the intake of seafood, EPA, and DHA and its relationship with sleep patterns warrants further exploration. Therefore, the present study aimed to investigate the association between seafood, EPA, and DHA intake at three different mealtimes, as well as from snacks, and both chronotype and social jetlag among Japanese adults.

MATERIALS AND METHODS

Ethical approval. This study was reviewed and

approved by the Ethical Committee for Epidemiology of Hiroshima University (approval number E2023-0199; UMIN000053972). All procedures were conducted in accordance with the ethical standards of the institutional and or national research committee and with the principles outlined in the Declaration of Helsinki. All methods in this cross-sectional study were performed according to the STROBE statement (24). Informed consent was obtained from all participants prior to their involvement in the study, and all participants agreed to their data being collected and used for research purposes.

Participants. In this cross-sectional study, we initially collected 9,711 responses to an online questionnaire from users of Asken, a Japanese mobile application that tracks diet, in March 2024. Participants were excluded if they were under 18 y of age, had abnormal height or weight values were shift workers, or exhibited extreme outliers in sleep variables. Extreme outliers were defined as values greater than the third quartile plus three times the interquartile range or less than the first quartile minus three times the interquartile range. This criterion was applied to minimize the influence of implausible values that may arise from reporting or input errors in large-scale self-reported data. After these exclusions, data from a total of 5,975 participants were included in the final analysis (Fig. 1).

Dietary data. The 1-mo dietary records from February to March 2024 from the Asken application were utilized. From these records, we calculated the average daily intake (g/d for seafood, mg/d for EPA and DHA, and kcal/d for energy) and per-meal consumption (g/meal for seafood and mg/meal for EPA and DHA at breakfast, lunch, dinner, and snacks). The analyses were based on monthly average intake values, and differences between workdays and free days were not examined separately. The intake of EPA and DHA was calculated based on participants' dietary records using nutrient values from the Standard Tables of Food Composition in Japan (2020 Edition, 8th Revision) (25). EPA and DHA values were available only for food items listed in the food composition tables that contained corresponding nutrient data. For food items without EPA or DHA information in the database, EPA and DHA intake was recorded as zero. In addition, EPA and DHA intake from dietary supplements was included when such information was explicitly provided on product labels and recorded in the application. Thus, total EPA and DHA intake represents the sum of values derived from foods and supplements with available nutrient information.

Questionnaire. The questionnaire consisted of 46 items designed to collect information on participants' demographic characteristics and sleep behaviors.

Demographic characteristics. The survey collected demographic characteristics potentially associated with sleep-related outcomes. The analyzed covariates included sex, age, body mass index, current smoking status (yes/no), current alcohol use (yes/no), annual income, and physical activity level (low, middle, high).

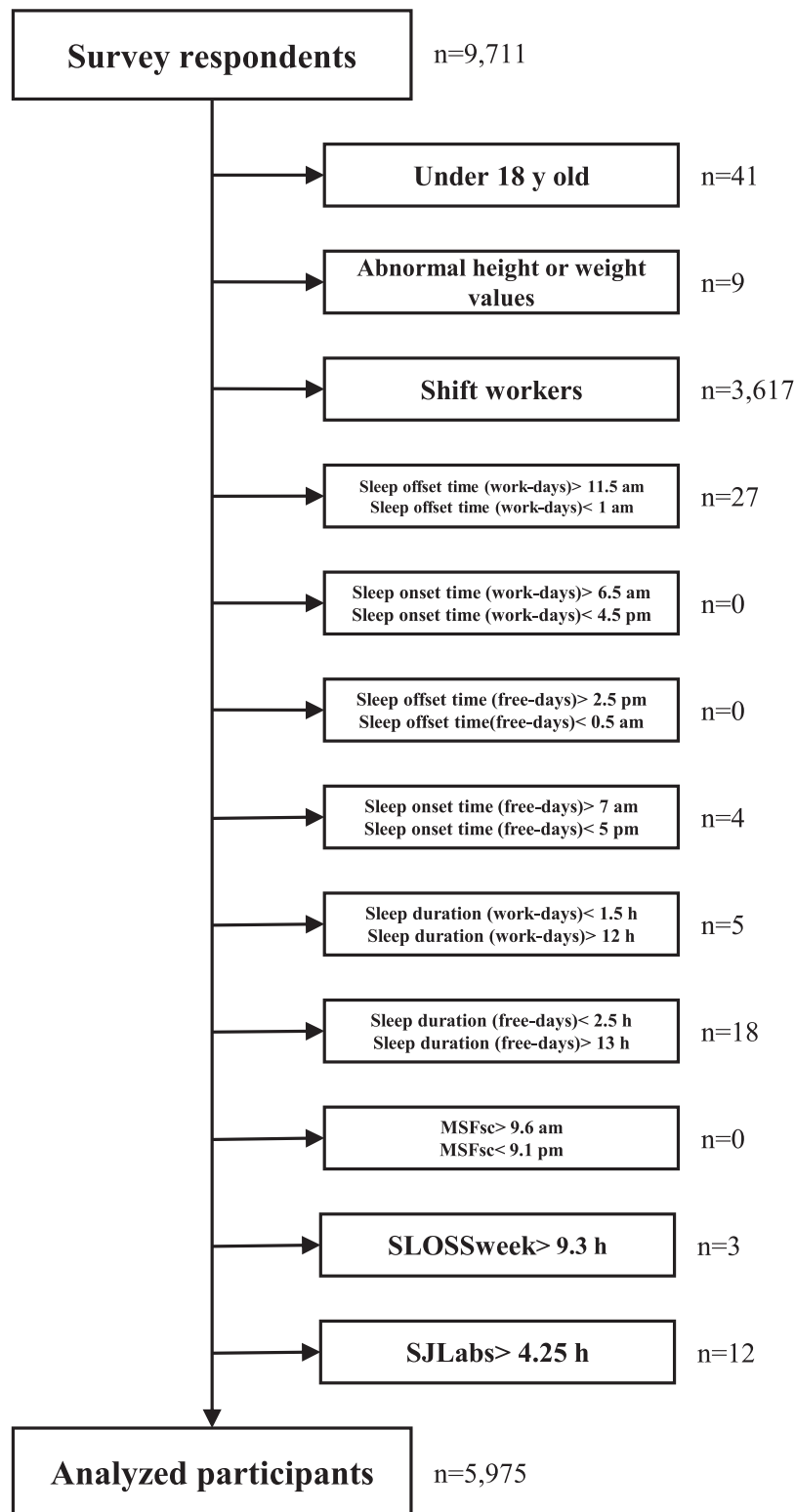


Fig. 1. Flow diagram of the participants. MSFsc, sleep-corrected mid-sleep time on free days; SJLabs, absolute social jetlag; SLOSSweek, sleep loss across the week.

Sleep patterns. Participants reported their sleep onset and offset times both on workdays and free days in 30-min increments. From this data, we calculated the sleep duration, sleep-corrected mid-sleep time on free days (MSFsc), and social jetlag assessed using the Munich Chronotype Questionnaire. MSFsc and social jetlag were selected as the primary outcomes. MSFsc

serves as a measure of chronotype, with lower values indicating a preference for a morning chronotype and reflecting earlier sleep patterns. Social jetlag represents the misalignment between sleep schedules on workdays and free days (26, 27).

Statistical analyses. Statistical analyses were conducted using IBM SPSS Statistics (version 27.0; IBM

Table 1. Demographic characteristics of the participants according to chronotype.

	Overall		Early		Moderately early		Moderately late		Late		p value
Number of participants, <i>n</i> (%)	5,975 (100%)		1,493 (25.0%)		1,419 (23.7%)		1,500 (25.1%)		1,563 (26.2%)		
Sex, <i>n</i> (%) ¹											<0.001**
Male	2,096 (35.1%)		678 (32.3%)		520 (24.8%)		481 (22.9%)		417 (19.9%)		
Female	3,879 (64.9%)		815 (21.0%)		899 (23.2%)		1,019 (25.1%)		1,146 (26.2%)		
Current smoking status, <i>n</i> (%) ¹											<0.001**
Yes	631 (10.6%)		167 (26.5%)		122 (19.3%)		134 (21.2%)		208 (33.0%)		
No	5,344 (89.4%)		1,326 (24.8%)		1,297 (24.3%)		1,366 (25.6%)		1,355 (25.4%)		
Current alcohol use, <i>n</i> (%) ¹											<0.001**
Yes	3,598 (60.2%)		890 (24.7%)		875 (24.3%)		887 (24.7%)		946 (26.3%)		
No	2,377 (39.8%)		2,377 (25.4%)		544 (22.9%)		613 (25.8%)		617 (26.0%)		
Physical activity level, <i>n</i> (%) ¹											<0.001**
Low	1,095 (18.3%)		232 (21.2%)		241 (22.0%)		254 (23.2%)		368 (33.6%)		
Middle	3,714 (62.2%)		866 (23.3%)		927 (25.0%)		969 (26.1%)		952 (25.6%)		
High	1,166 (19.5%)		395 (33.9%)		251 (21.5%)		277 (23.8%)		243 (20.8%)		
	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	
Age (y) ²	46	18	50	15	48	17	45	18	41	16	<0.001**
Body mass index (kg/m ²) ²	22.59	4.85	22.57	4.68	22.40	4.82	22.57	4.85	22.89	5.09	0.015*

¹ *p* value, chi-square test.² *p* value, Kruskal–Wallis test.**p*<0.05; ***p*<0.001.

IQR, interquartile range.

Table 2. Sleep patterns of the participants according to chronotype.

	Overall		Early		Moderately early		Moderately late		Late		p value
	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	
Sleep offset time on workdays (hh:mm)	6:00	1:30	5:00	1:00	6:00	1:00	6:30	1:00	7:00	1:30	<0.001**
Sleep onset time on workdays (hh:mm)	23:30	2:00	22:00	1:30	23:00	1:00	0:00	1:00	1:00	1:30	<0.001**
Sleep offset time on free days (hh:mm)	7:30	2:00	6:00	1:30	7:00	1:00	7:30	1:30	9:00	1:30	<0.001**
Sleep onset time on free days (hh:mm)	0:00	2:00	22:00	1:00	23:30	0:30	0:00	0:30	1:30	1:00	<0.001**
Sleep duration on workdays (hh:mm)	6:30	1:30	7:00	1:30	7:00	1:30	6:30	1:30	6:30	1:30	<0.001**
Sleep duration on free days (hh:mm)	7:30	1:30	7:30	1:30	8:00	1:30	7:30	2:00	7:30	1:30	<0.001**
MSFsc (hh:mm)	3:15	1:43	1:47	1:00	2:04	1:00	3:36	1:00	4:51	1:00	<0.001**
Social jetlag (hh:mm)	0:45	1:00	0:15	0:45	0:30	0:45	0:45	0:45	1:30	1:00	<0.001**

p value, Kruskal–Wallis test.***p*<0.001.

IQR, interquartile range; MSFsc, sleep-corrected mid-sleep time on free days.

Corp., Armonk, NY, USA). Descriptive statistics are presented as numbers and percentages for categorical data, or as medians with interquartile ranges for continuous data. Participants were classified into four groups according to the quartiles of their MSFsc values, representing early, moderately early, moderately late, and late chronotypes. Differences between the four groups were

assessed using the chi-square test for categorical variables and the Kruskal–Wallis test for continuous variables. Generalized estimating equations (GEEs) were used to examine the impact of dietary intake on sleep patterns. The dependent variables (MSFsc and social jetlag) were treated as continuous variables, whereas the independent variables (daily, breakfast, lunch, dinner,

Table 3. Dietary patterns of the participants according to chronotype.

	Overall			Early			Moderately early			Moderately late			Late			p value
	Median	IQR		Median	IQR		Median	IQR		Median	IQR		Median	IQR		
Energy intake Seafood	Daily (kcal)	1,699.00	495.50	1,755.00	555.00		1,697.00	495.00		1,696.00	482.00		1,651.00	456.00		<0.001**
	Daily (g)	32.00	31.00	35.00	33.00		34.00	31.00		31.00	29.00		27.00	28.00		<0.001**
	Breakfast (g)	1.00	4.00	1.00	6.00		1.00	4.00		0.00	3.00		0.00	2.00		<0.001**
	Lunch (g)	8.00	11.00	8.00	13.00		8.00	11.00		8.00	12.00		6.00	11.00		<0.001**
	Dinner (g)	19.00	22.00	20.00	23.00		20.00	22.00		19.00	21.00		17.00	20.00		<0.001**
	Snacks (g)	0.00	0.00	0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00		0.997
EPA	Daily (mg)	140.40	137.95	156.00	149.90		144.90	133.90		137.35	135.90		127.70	124.60		<0.001**
	Breakfast (mg)	4.30	17.65	7.60	27.30		4.80	17.30		3.70	15.90		2.60	11.60		<0.001**
	Lunch (mg)	33.50	53.90	36.00	58.30		35.80	54.80		34.30	52.80		27.90	48.60		<0.001**
	Dinner (mg)	75.70	91.15	80.30	98.40		77.50	93.10		75.40	85.40		69.80	84.90		0.001*
	Snacks (mg)	0.50	1.40	0.30	1.20		0.40	1.20		0.60	1.30		0.60	1.50		<0.001**
	Daily (mg)	261.50	223.30	290.30	245.80		264.50	219.20		257.90	223.10		236.80	211.20		<0.001**
DHA	Breakfast (mg)	16.40	37.65	25.80	52.20		19.60	36.30		14.85	34.50		9.80	29.50		<0.001**
	Lunch (mg)	66.10	90.40	70.00	97.00		68.80	94.00		67.85	87.60		58.30	82.30		<0.001**
	Dinner (mg)	136.50	147.00	143.50	161.80		139.30	150.60		135.90	137.00		128.50	141.50		0.015*
	Snacks (mg)	2.10	4.40	1.60	4.40		1.90	4.20		2.40	4.30		2.60	4.70		<0.001**

p value, Kruskal–Wallis test.
* $p<0.05$; ** $p<0.001$.

DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; IQR, interquartile range.

Daily intake is expressed as kcal/d for energy, g/d for seafood and mg/d for EPA and DHA, calculated as monthly averages from 1-mo dietary records. Meal-specific intake represents average intake per meal (g/meal or mg/meal). Chronotype was classified as early, moderately early, moderately late, or late based on MSFsc. Values are presented as median and IQR.

Table 4. Association between daily seafood, eicosapentaenoic acid, and docosahexaenoic acid intake and for chronotype and or social jetlag using generalized estimating equation analysis.

Dependent variable	Parameter	B	SE	95% confidence interval for B		Wald chi-square	p value
				Lower	Upper		
MSFsc	Seafood	−0.123	0.034	−0.190	−0.056	12.8	<0.001**
	EPA	−0.090	0.034	−0.158	−0.023	6.886	0.009*
	DHA	−0.097	0.035	−0.165	−0.029	7.783	0.005*
Social jetlag	Seafood	−0.061	0.018	−0.096	−0.026	11.598	0.001*
	EPA	−0.045	0.018	−0.080	−0.010	6.481	0.011*
	DHA	−0.035	0.018	−0.070	0.000	3.881	0.049*

* $p < 0.05$; ** $p < 0.001$.

B, unstandardized regression coefficient; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; MSFsc, sleep-corrected mid-sleep time on free days; SE, standard error.

Generalized estimating equation (GEE) models were used. Intake variables were dichotomized into high and low groups based on median values. B coefficients represent differences between intake categories. Models were adjusted for sex, age, body mass index, current smoking status, current alcohol use, income, physical activity, sleep duration on workdays and free days, and total energy intake.

and snack intake of seafood, EPA and DHA) were categorized as dichotomous. Except for seafood intake at snack times, which were categorized as consumed or not consumed, other intake variables were divided into two groups—the low and high intake groups—based on the median value. Because effect estimates per unit of intake would be difficult to interpret in a practical context, meal-specific intakes of seafood, EPA, and DHA were dichotomized using median splits to enhance interpretability. The reference group comprised participants in the low-intake or not-consumed category. Covariates included sex, age, body mass index, annual income, current smoking status, current alcohol use, physical activity level, sleep duration on workdays and free days, and daily energy intake. Statistical significance was defined as $p < 0.05$.

RESULTS

Participant characteristics

The demographic characteristics of the participants are presented in Table 1, including sex, physical activity level, age, and body mass index. Of the 5,975 participants included, 64.9% were female and 35.1% were male. The distribution of chronotypes showed significant differences between the sexes ($p < 0.001$). Among male participants, the early chronotype group showed the highest proportion (32.3%), and the number gradually decreased from early to late chronotypes. By contrast, among female participants, the distribution was reversed, with the late chronotype group showing the highest proportion (26.2%). In addition, significant differences were observed in current smoking status ($p < 0.001$) and alcohol use ($p < 0.001$) across chronotype groups. Significant differences were also observed in chronotype distribution across physical activity levels ($p < 0.001$). Participants with low levels of physical activity were most represented in the late chronotype group (33.6%) and least in the early group (21.2%).

Those with middle levels of activity had the highest proportion in the moderately late chronotype group (26.1%) and the lowest in the early group (23.3%). Conversely, participants with high levels of physical activity were most represented in the early chronotype group (33.9%) and least in the late group (20.8%). Participants with a later chronotype were more likely to be younger ($p < 0.001$) and have a higher body mass index ($p = 0.015$).

Table 2 presents the sleep-related variables, including sleep onset and offset times, and sleep duration on workdays and free days, as well as MSFsc and social jetlag. The medians of MSFsc and social jetlag for participants were 3 h and 15 min and 45 min, respectively. Individuals with a later chronotype showed greater social jetlag ($p < 0.001$).

Daily and meal-specific dietary intake are presented in Table 3, including energy, seafood, EPA, and DHA. The intake of EPA and DHA includes contributions from both food sources and supplements. Compared to those with earlier chronotypes, participants with later chronotypes had lower energy intake and lower seafood consumption at breakfast ($p < 0.001$), lunch ($p < 0.001$), and dinner ($p < 0.001$). Similarly, EPA and DHA intake was lower at breakfast ($p < 0.001$ for both), lunch ($p < 0.001$ for both), and dinner ($p = 0.001$ and $p = 0.015$, respectively). By contrast, those with a later chronotype had higher EPA and DHA intake from snacks ($p < 0.001$ for both).

Association between seafood, EPA, and DHA intake with chronotype and social jetlag

Table 4 presents the associations between daily intake of seafood, EPA, and DHA and sleep behaviors, analyzed using GEEs. Using the low-intake group as the reference, we found that higher daily intake of seafood, EPA, and DHA was associated with a morning chronotype (earlier MSFsc), indicating earlier sleep patterns. Participants with higher seafood and EPA intake also showed

Table 5. Association between seafood, eicosapentaenoic acid, and docosahexaenoic acid intake at different mealtimes and for chronotypes using generalized estimating equation analysis.

Parameter		B	SE	95% confidence intervals for B		Wald chi-square	p value
				Lower	Upper		
Seafood	Breakfast ¹	-0.317	0.034	-0.384	-0.251	88.442	<0.001**
	Lunch ¹	-0.082	0.034	-0.149	-0.016	5.884	0.015*
	Dinner ¹	0.000	0.035	-0.069	0.068	0.000	0.994
	Snacks ²	0.081	0.057	-0.030	0.193	2.048	0.152
EPA	Breakfast ¹	-0.326	0.034	-0.392	-0.261	94.951	<0.001**
	Lunch ¹	-0.062	0.034	-0.128	0.004	3.403	0.065
	Dinner ¹	0.048	0.034	-0.019	0.115	1.998	0.158
	Snacks ¹	0.237	0.033	0.171	0.302	50.368	<0.001**
DHA	Breakfast ¹	-0.344	0.034	-0.410	-0.278	104.101	<0.001**
	Lunch ¹	-0.076	0.033	-0.141	-0.010	5.140	0.023*
	Dinner ¹	0.047	0.034	-0.020	0.113	1.872	0.171
	Snacks ¹	0.182	0.034	0.116	0.248	29.429	<0.001**

¹ Intake parameters were divided into low and high groups based on the median.

² Intake was categorized into the consumed and not consumed groups.

* $p < 0.05$; ** $p < 0.001$.

B, unstandardized regression coefficient; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; SE, standard error.

Generalized estimating equation (GEE) models were used. The dependent variable was chronotype (MSFsc). Intake variables were dichotomized into high and low groups based on median values, or categorized as consumed versus not consumed, as appropriate. B coefficients represent differences between intake categories. Models were adjusted for sex, age, body mass index, current smoking status, current alcohol use, income, physical activity, sleep duration on workdays and free days, and total energy intake.

less social jetlag.

To examine whether the timing of consumption was associated with sleep patterns, we conducted a GEE analysis including seafood, EPA, and DHA intake at breakfast, lunch, dinner, and snacks were simultaneously included in a single model. The results for chronotype (MSFsc) are presented in Table 5. Compared with the low-intake group, participants with higher seafood, EPA, and DHA intake at breakfast (seafood: $B = -0.317$, $p < 0.001$; EPA: $B = -0.326$, $p < 0.001$; DHA: $B = -0.344$, $p < 0.001$) and lunch (seafood: $B = -0.082$, $p = 0.015$; DHA: $B = -0.076$, $p = 0.023$) exhibited significantly earlier MSFsc values, indicating a tendency toward morningness. By contrast, greater EPA and DHA intake from snacks (EPA: $B = 0.237$, $p < 0.001$; DHA: $B = 0.182$, $p < 0.001$) was associated with a later chronotype. Intake at dinner was not significantly associated with chronotype.

Results for social jetlag are reported in Table 6. Similar to the findings for chronotype, participants with higher intake of seafood, EPA, and DHA at breakfast (seafood: $B = -0.096$, $p < 0.001$; EPA: $B = -0.085$, $p < 0.001$; DHA: $B = -0.088$, $p < 0.001$) and lunch (seafood: $B = -0.036$, $p = 0.043$; EPA: $B = -0.036$, $p = 0.039$; DHA: $B = -0.042$, $p = 0.015$) exhibited significantly less social jetlag. Greater EPA and DHA intake from snacks (EPA: $B = 0.052$, $p = 0.003$; DHA: $B = 0.050$, $p = 0.004$) was associated with greater social jetlag, whereas a significant association at dinner was

observed only for seafood intake ($B = -0.037$, $p = 0.041$).

We conducted an additional GEE analysis focusing on breakfast intake. These results are presented in Table S1 (Supplemental Online Material). After additional adjustment for breakfast energy intake, higher breakfast seafood, EPA, and DHA intake remained significantly associated with earlier MSFsc. In addition, breakfast seafood and EPA intake remained significantly associated with lower social jetlag.

DISCUSSION

In the present study, we investigated the associations between seafood, EPA, and DHA consumption at different mealtimes and sleep patterns; specifically, we investigated chronotype and social jetlag in an adult Japanese population. Overall, our findings demonstrated that a significant relationship exists between these dietary components and sleep characteristics: Higher daily intake of seafood, EPA, and DHA were negatively associated with the MSFsc, indicating a tendency toward a morning chronotype. Furthermore, greater seafood and EPA consumption were linked to less social jetlag. These results suggest that participants with higher overall intake of these nutrients were more likely to exhibit earlier sleep patterns and maintain more consistent sleep schedules between workdays and free days compared to those with lower intake. Moreover, our results reveal that the timing of consumption was dif-

Table 6. Association between seafood, eicosapentaenoic acid, and docosahexaenoic acid intake at different meals and for social jetlag using generalized estimating equation analysis.

		<i>B</i>	SE	95% confidence interval for <i>B</i>		Wald chi-square	<i>p</i> value
				Lower	Upper		
Seafood	Breakfast ¹	−0.096	0.018	−0.130	−0.062	29.924	<0.001**
	Lunch ¹	−0.036	0.018	−0.070	−0.001	4.114	0.043*
	Dinner ¹	−0.037	0.018	−0.073	−0.001	4.164	0.041*
	Snacks ²	0.008	0.029	−0.049	0.065	0.072	0.789
EPA	Breakfast ¹	−0.085	0.017	−0.119	−0.051	23.674	<0.001**
	Lunch ¹	−0.036	0.018	−0.071	−0.002	4.243	0.039*
	Dinner ¹	−0.022	0.018	−0.057	0.013	1.528	0.216
	Snacks ¹	0.052	0.017	0.018	0.086	9.063	0.003*
DHA	Breakfast ¹	−0.088	0.017	−0.122	−0.054	25.679	<0.001**
	Lunch ¹	−0.042	0.017	−0.076	−0.008	5.899	0.015*
	Dinner ¹	−0.014	0.018	−0.049	0.021	0.631	0.427
	Snacks ¹	0.050	0.018	0.016	0.085	8.251	0.004*

¹ Intake parameters were divided into low and high groups based on the median.

² Intake was categorized into the consumed and not consumed groups.

* $p < 0.05$; ** $p < 0.001$.

B, unstandardized regression coefficient; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; SE, standard error.

Generalized estimating equation (GEE) models were used. The dependent variable was social jetlag. Intake variables were dichotomized into high and low groups based on median values, or categorized as consumed versus not consumed, as appropriate. B coefficients represent differences between intake categories. Models were adjusted for sex, age, body mass index, current smoking status, current alcohol use, income, physical activity, sleep duration on workdays and free days, and total energy intake.

ferentially associated with sleep outcomes. Specifically, higher intake of seafood, EPA, and DHA at breakfast and lunch was significantly associated with both an earlier chronotype, indicated by an earlier MSFsc, and less social jetlag.

The exact and comprehensive mechanisms underlying the observed associations between seafood, EPA, and DHA intake and earlier sleep patterns or less social jetlag remain unclear. However, one possible interpretation is that higher intake of EPA and DHA may be associated with better sleep quality, which could be related to smaller differences in sleep timing and duration between workdays and free days. Seafood—especially fatty fish—is rich in long-chain n-3 PUFAs, vitamin D, and tryptophan, all of which have been linked to sleep quality, and regulation of the sleep–wake cycle (16, 18, 23, 28).

Firstly, EPA and DHA are crucial structural components of cell membranes throughout the body (29). Evidence from cell and animal studies has shown that DHA is abundant in the brain and plays key roles in neurotransmission, membrane stability, and signal transduction (16, 18, 30). Increased levels of EPA and DHA can modify the membrane structure and protein function, as well as modulate the production of bioactive lipid mediators (16, 29–31). These fatty acids reduce the synthesis of pro-inflammatory mediators and give rise to anti-inflammatory or inflammation-resolving mediators (16). Given the link between inflamma-

tion and sleep disturbances observed in humans, the anti-inflammatory properties of n-3 PUFAs may contribute to improved sleep by reducing neuroinflammation (2, 18).

Secondly, biological evidence suggests that EPA and DHA are involved in neuroendocrine regulation. DHA has been shown to support the enzymatic conversion of serotonin to melatonin, a key hormone in the regulation of circadian rhythms (22, 30). Animal studies have demonstrated that a deficiency in n-3 PUFAs can disturb melatonin secretion (13). Furthermore, EPA and DHA can modulate the function of neurotransmitters such as serotonin and dopamine, which are crucial for mood and sleep regulation (16). For instance, previous animal research has found that a higher DHA intake has been positively associated with increased levels of sleep-related substances in the hippocampus (2). However, the reason why intake at breakfast and or lunch may modulate such transmitter systems remains unknown.

Thirdly, EPA and DHA have been suggested to regulate peripheral circadian clocks based primarily on evidence from animal studies (32). Evidence from animal studies suggests that these fatty acids can induce circadian phase resetting by modulating the release of insulin (32, 33). Furutani et al. found that diets rich in fish oil or containing EPA and or DHA significantly accelerate diet-induced entrainment of the peripheral clock in mice (33). This effect may involve enhanced secretion

of glucagon-like peptide-1 and insulin, activation of G-protein-coupled receptor 120, and upregulation of the core clock gene *Period* Circadian Regulator 2 in mice (33). However, direct evidence supporting these mechanisms in humans remains limited. Therefore, while these animal-based findings provide a plausible biological pathway, the relevance of these pathways to dietary timing and circadian phase regulation in humans remains speculative.

Finally, seafood is a source of other sleep-regulating nutrients. Fatty fish is a major dietary source of vitamin D (22, 28). Epidemiological studies indicate that vitamin D deficiency is associated with a higher risk of sleep disorders, poor sleep quality, and short sleep duration, potentially through its influence on brain regions involved in sleep regulation (18, 22, 28). Tryptophan, an essential amino acid abundant in high-quality protein sources such as fish, is a precursor to both serotonin and melatonin (18, 22). Interestingly, intervention studies in humans have shown that intake of tryptophan-rich protein at breakfast, but not dinner, can increase melatonin secretion (34). The combined effects of various nutrients found in seafood may explain why their intake is associated with sleep patterns.

The varying statistical significance observed across mealtimes confirms the crucial role of timing of nutrient intake in relation to sleep. Even though the consumption of food at dinner might be major, it was consumption at breakfast and lunch that were significantly associated with an earlier chronotype and less social jetlag, with breakfast showing the strongest association. These results are consistent with previous studies indicating that breakfast may be more strongly associated with sleep and circadian-related outcomes (32). In other words, the timing of nutrient intake—particularly in the morning—may play a central role in aligning circadian rhythms. This alignment may potentially contribute to earlier sleep phases and smaller discrepancies between the timing of sleep on workdays and free days, possibly through better synchronization of internal biological clocks (32). Several studies have reported that individuals who skip breakfast have a significantly later chronotype and exhibit a phase delay in core body temperature of 1 h (35, 36). This may also relate to the dietary habits of Japanese individuals. Prior research has shown that individuals with a morning chronotype tend to have a higher daily protein intake (4, 37). A cross-sectional study further revealed that consumption of proteins at breakfast was positively associated with a morning chronotype and less social jetlag among Japanese adults (19). These findings suggest that the timing of protein intake—particularly at breakfast—may play an important role in regulating circadian rhythms. Associations have also been observed between breakfast style and chronotype. A Japanese-style breakfast, which typically includes fish, has been associated with greater protein intake and a morning chronotype and or smaller MSFsc values (21, 31). By contrast, individuals who have Western-style and cereal-based breakfasts are linked to a later chronotype and increased social jetlag

(9, 21).

The impact of dietary components may differ according to the timing of intake (38). Experiments using a mouse model have shown that the absorption efficiency of n-3 PUFA may be enhanced when it is consumed in the morning (38, 39). In a Japanese intervention study, intake of fish oil (DHA and EPA) at breakfast, rather than at dinner, significantly decreased serum triglyceride levels (38). These findings suggest that the amount as well as the timing of taking in fish oil may be important for the physiological effects it has in humans (38). Accordingly, consuming seafood containing fish oil earlier in the day may contribute to regulation of circadian rhythms, as observed in those with a morning chronotype, and lower levels of social jetlag, but also reductions in the levels of serum triglycerides.

Conversely, our results indicate that EPA and DHA consumption from snacks was associated with a later chronotype and greater social jetlag. Although we did not collect data on the exact time of snack consumption, this finding is consistent with previous research reporting associations between snacking behaviors and circadian-related outcomes (40–42). One possible interpretation is that EPA and DHA intake from snacks may be associated with eating patterns that are also linked to later circadian clock (40). Individuals with an evening chronotype have been reported to consume snacks more frequently than those with a morning chronotype (40, 41). However, because the timing of snack consumption was not assessed in the present study, the underlying mechanisms linking snack-derived intake to sleep outcomes cannot be determined.

To our knowledge, this is the first study to investigate the associations between the consumption of seafood, EPA, and DHA at different meals with both chronotype and social jet lag. Our findings suggest that what is consumed and when it is consumed may both be important for sleep patterns.

Several limitations of the present study should be noted. First, because of the cross-sectional design, causal relationships cannot be established. Although significant associations were observed between the timing of seafood, EPA, and DHA intake and sleep-related outcomes, it remains unclear whether dietary timing influences chronotype and social jetlag or whether an individual's chronotype influences eating behavior. In addition, meal-specific intakes were categorized using median splits, which may have obscured dose-response relationships or more subtle variations in intake. Second, dietary intake was self-reported using a mobile food-logging application, which may be subject to recall bias, misreporting, and under- or overestimation of specific foods or nutrients. Although dietary records were collected over a one-month period, inaccuracies in portion size estimation and selective reporting cannot be ruled out. Furthermore, EPA and DHA intake could only be estimated for foods and supplements with available nutrient data, potentially leading to underestimation of total intake. Third, although our sample included participants across a wide range of ages and from diverse

regions throughout Japan, the study population consisted of users of a mobile dietary application that is primarily used for weight management, and approximately 65% of the participants were women. Individuals who actively use diet-tracking applications may have higher health consciousness and distinct dietary and lifestyle behaviors compared with the general population. This potential selection bias may limit the generalizability of the findings to the broader Japanese population or to other demographic groups. Fourth, we assessed seafood, EPA, and DHA intake at breakfast, lunch, dinner, and from snacks, but did not collect information on the exact timing of intake. This lack of temporal precision limited our ability to investigate more detailed timing effects, particularly with respect to snacking. In addition, although several lifestyle-related confounders were considered in the present analyses, other factors known to relate to sleep and circadian rhythms—such as caffeine intake, meal timing, and meal regularity—were not available in the dataset. Caffeine acts as an adenosine antagonist that not only delays sleep onset but also reduces sleep pressure and quality (43, 44). Furthermore, meal timing and regularity serve as peripheral zeitgebers; late or irregular eating patterns can desynchronize circadian clocks, leading to sleep disturbances (45). Consequently, the absence of these variables limits our ability to rule out the potential influence of residual confounding on the observed associations.

Further studies are needed to investigate the chronobiological effects of timing of seafood, EPA and DHA intake on sleep and circadian rhythms. Longitudinal or interventional studies will be necessary to establish causal relationships and examine the long-term impact of timed nutrient intake on sleep outcomes. Based on our findings, seafood, EPA, and DHA intake at different mealtimes may have potential relevance for sleep health, and further research is needed to explore the underlying biological mechanisms.

To conclude, the present study identified significant associations between seafood, EPA, and DHA intake and sleep patterns. Of note, is that higher consumption of these nutrients at breakfast and lunch was associated with an earlier chronotype and less social jetlag. Conversely, intake from snacks appeared to be related to a later chronotype and greater social jetlag. These findings suggest that the amount as well as the timing of seafood, EPA, and DHA intake are associated with sleep-related outcomes. This research provides a foundation for future intervention studies to establish causal relationships, explore underlying biological mechanisms, and inform the development of evidence-based, personalized dietary recommendations for sleep health.

Authorship

Research conception and design: YL and YT; methodology and data collection: YL, YT, EY, KU, and SS; statistical analysis of the data: YL and YT; writing of the manuscript: YL and YT; supervision: KU, EY, and SS. All authors have read and agreed to the published version of the manuscript.

Disclosure of state of COI

KU and EY are employees of Nissui Corporation. This study was financially supported by Nissui. All the other authors declared no competing interests.

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Supporting information

Supplemental online material is available on J-STAGE.

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