Association of maternal sleep before and during pregnancy with sleep and developmental problems in 1-year-old infants

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This study investigated the association of maternal sleep before and during pregnancy with sleeping and developmental problems in 1-year-old infants. We used data from the Japan Environment and Children's Study, which registered 103,062 pregnancies between 2011 and 2014. Participants were asked about their sleep habits prior to and during pregnancy. Follow-up assessments were conducted to evaluate the sleep habits and developmental progress of their children at the age of 1 year. Development during infancy was evaluated using the Ages and Stages Questionnaire (ASQ). Maternal short sleep and late bedtime before and during pregnancy increased occurrence of offspring's sleeping disturbances. For example, infants whose mothers slept for less than 6 h prior to pregnancy tended to be awake for more than 1 h (risk ratio [RR] = 1.49, 95% confidence interval [CI] 1.34–1.66), sleep less than 8 h during the night (RR = 1.60, 95% CI 1.44–1.79), and fall asleep at 22:00 or later (RR = 1.33, 95% CI 1.26–1.40). Only subjective assessments of maternal sleep quality during pregnancy, such as very deep sleep and feeling very good when waking up, were inversely associated with abnormal ASQ scores in 1-year-old infants.

Sleep duration among the general population in Japan has been reported to be shorter than that in other countries1 and has become even shorter in recent years2. Furthermore, it has been reported that approximately 10% of infants have sleeping problems3. Neurodevelopmental disorders, including autism spectrum disorder (ASD), neurodevelopment abnormalities, and disturbed sleep habits, such as late bedtime and intense night crying, are observed in early infancy4. The incidence of developmental disorders is increasing in developed countries, including Japan5–7. Factors related to developmental disorders include genetic ones and environmental (in utero) ones8,9. Maternal lifestyle such as sleep pattern may affect the offspring's sleep and development.

It has been reported that maternal sleep disorders are associated with developmental progress in the offspring. For example, maternal sleep disordered breathing (SDB) during pregnancy is associated with the offspring's development, manifesting as disrupted social skills and low reading-test scores10,11. Thus, not only maternal sleep habit but also maternal sleep disorders during pregnancy may be related to early infant sleep patterns and

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development. However, no large-scale study has examined the potential associations between maternal sleep and the offspring's sleep patterns or development. Additionally, the importance of maternal sleep during various periods of pregnancy and the persistence of the influence remain unclear.

We previously reported that maternal sleep habits, such as short sleep duration and late bedtime, both before and during pregnancy, were associated with the offspring's sleep problems and temperament at 1 month of age. We hypothesize that maternal sleep before and during pregnancy would continue to be associated with the infant's sleep and developmental problems even at 1 year of age.

This study aimed to expand on those findings and investigate the association between maternal sleep habits, before and during pregnancy, with offspring outcomes at 1 year of age.

### Results

The baseline characteristics of the participants, along with the available data on sleep duration before pregnancy, are shown in Table 1. The characteristics of participants in the various sleep groups are also shown in Supplemental Table 1. The reported sleep duration was on average between 7 and 8 h, both before and during pregnancy. The participants tended to sleep longer and go to bed earlier during pregnancy than before pregnancy. Significant data points are summarized below and include risk ratios (RR) and 95% confidence intervals (CI) in the multivariable model, adjusted for maternal age at delivery, smoking habits, alcohol consumption, pre-pregnancy body mass index, gestational age at birth, parity, infertility treatment, and infant sex.

### Maternal sleep before pregnancy (Table 2)

Short sleep duration less than 6 h before pregnancy was associated with a higher risk of night waking for ≥ 1 h (RR = 1.49, 95% CI 1.34–1.66),

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Table 1. Baseline characteristics of the study population stratified by sleep duration before pregnancy.
| No. of participants | No. of outcome | Maternal age adjusted model | Multivariable model* |
|---------------------|---------------|-----------------------------|----------------------|
|                     |               | %      | RR  | 95% CI    | RR  | 95% CI    |
| > 3 nighttime waking instances |
| Sleep duration |
| < 6 h       | 4948         | 118    | 2.4 | 1.04 | 0.85 | 1.26 | 1.08 | 0.89 | 1.32 |
| 6 < 7       | 14,661       | 324    | 2.2 | 0.95 | 0.83 | 1.09 | 0.96 | 0.84 | 1.10 |
| 7 < 8       | 25,136       | 584    | 2.3 | Ref  | Ref  | Ref  | Ref  | Ref  | Ref  |
| 8 < 9       | 18,302       | 466    | 2.6 | 1.10 | 0.98 | 1.24 | 1.09 | 0.96 | 1.23 |
| 9 < 10      | 7494         | 209    | 2.8 | 1.23 | 1.05 | 1.43 | 1.20 | 1.02 | 1.40 |
| 10<         | 3286         | 74     | 2.3 | 1.06 | 0.84 | 1.35 | 1.07 | 0.84 | 1.36 |
| Bedtime     |
| 21 < 24     | 49,995       | 1275   | 2.6 | Ref  | Ref  | Ref  | Ref  | Ref  | Ref  |
| 24 < 27     | 21,825       | 461    | 2.1 | 0.85 | 0.76 | 0.94 | 0.89 | 0.80 | 0.99 |
| Other       | 2007         | 39     | 1.9 | 0.83 | 0.61 | 1.14 | 0.90 | 0.65 | 1.23 |
| > 1 waking instances lasting > 1 h |
| Sleep duration |
| < 6 h       | 4948         | 411    | 8.3 | 1.54 | 1.38 | 1.71 | 1.49 | 1.34 | 1.66 |
| 6 < 7       | 14,661       | 929    | 6.3 | 1.18 | 1.09 | 1.28 | 1.16 | 1.07 | 1.26 |
| 7 < 8       | 25,136       | 1343   | 5.3 | Ref  | Ref  | Ref  | Ref  | Ref  | Ref  |
| 8 < 9       | 18,302       | 916    | 5.0 | 0.94 | 0.86 | 1.02 | 0.96 | 0.89 | 1.04 |
| 9 < 10      | 7494         | 387    | 5.2 | 0.96 | 0.86 | 1.07 | 1.00 | 0.90 | 1.12 |
| 10<         | 3286         | 224    | 6.8 | 1.24 | 1.08 | 1.42 | 1.25 | 1.09 | 1.14 |
| Bedtime     |
| 21 < 24     | 49,995       | 2460   | 4.9 | Ref  | Ref  | Ref  | Ref  | Ref  | Ref  |
| 24 < 27     | 21,825       | 1550   | 7.1 | 1.44 | 1.35 | 1.53 | 1.38 | 1.30 | 1.47 |
| Other       | 2007         | 200    | 10.0| 1.99 | 1.73 | 2.28 | 1.92 | 1.67 | 2.21 |
| < 8 h of sleep during the night (20:00–7:59) |
| Sleep duration |
| < 6 h       | 4948         | 408    | 8.3 | 1.65 | 1.48 | 1.84 | 1.60 | 1.44 | 1.79 |
| 6 < 7       | 14,661       | 872    | 6.0 | 1.21 | 1.11 | 1.31 | 1.19 | 1.09 | 1.29 |
| 7 < 8       | 25,136       | 1233   | 4.9 | Ref  | Ref  | Ref  | Ref  | Ref  | Ref  |
| 8 < 9       | 18,302       | 804    | 4.4 | 0.89 | 0.82 | 0.98 | 0.92 | 0.84 | 1.00 |
| 9 < 10      | 7494         | 319    | 4.3 | 0.86 | 0.77 | 0.97 | 0.90 | 0.80 | 1.02 |
| 10<         | 3286         | 207    | 6.3 | 1.25 | 1.08 | 1.44 | 1.26 | 1.09 | 1.46 |
| Bedtime     |
| 21 < 24     | 49,995       | 2284   | 4.6 | Ref  | Ref  | Ref  | Ref  | Ref  | Ref  |
| 24 < 27     | 21,825       | 1361   | 6.2 | 1.37 | 1.28 | 1.46 | 1.31 | 1.22 | 1.40 |
| Other       | 2007         | 198    | 9.9 | 2.11 | 1.84 | 2.43 | 2.04 | 1.77 | 2.35 |
| Falling asleep at 22:00 or later |
| Sleep duration |
| < 6 h       | 4948         | 1363   | 27.6| 1.39 | 1.32 | 1.46 | 1.33 | 1.26 | 1.40 |
| 6 < 7       | 14,661       | 3359   | 22.9| 1.17 | 1.13 | 1.22 | 1.15 | 1.10 | 1.19 |
| 7 < 8       | 25,136       | 4898   | 19.5| Ref  | Ref  | Ref  | Ref  | Ref  | Ref  |
| 8 < 9       | 18,302       | 3348   | 18.3| 0.94 | 0.90 | 0.97 | 0.96 | 0.92 | 1.00 |
| 9 < 10      | 7494         | 1183   | 15.8| 0.80 | 0.76 | 0.85 | 0.84 | 0.79 | 0.89 |
| 10<         | 3286         | 691    | 21.0| 1.02 | 0.95 | 1.10 | 1.02 | 0.95 | 1.10 |
| Bedtime     |
| 21 < 24     | 49,995       | 8412   | 16.8| Ref  | Ref  | Ref  | Ref  | Ref  | Ref  |
| 24 < 27     | 21,825       | 5935   | 27.2| 1.60 | 1.55 | 1.65 | 1.53 | 1.48 | 1.58 |
| Other       | 2007         | 495    | 24.7| 1.40 | 1.29 | 1.52 | 1.34 | 1.23 | 1.45 |
| Frequency of crying at night (≥ 5 days/week) |
| Sleep duration |
| < 6 h       | 4948         | 395    | 8.0 | 1.14 | 1.03 | 1.27 | 1.16 | 1.05 | 1.29 |
| 6 < 7       | 14,661       | 1085   | 7.4 | 1.05 | 0.98 | 1.13 | 1.05 | 0.98 | 1.13 |
| 7 < 8       | 25,136       | 1771   | 7.1 | Ref  | Ref  | Ref  | Ref  | Ref  | Ref  |
| 8 < 9       | 18,302       | 1345   | 7.4 | 1.05 | 0.98 | 1.12 | 1.05 | 0.98 | 1.12 |
| 9 < 10      | 7494         | 548    | 7.3 | 1.04 | 0.95 | 1.15 | 1.05 | 0.96 | 1.15 |
| Continued   |
pregnancy, offspring of mothers who slept after midnight had a higher risk of night waking for > 1 h (RR = 1.38, 95% CI 1.23–1.55), and falling asleep at 22:00 or later (RR = 1.08, 95% CI 1.01–1.15). Compared to offspring of mothers who slept before midnight before pregnancy, offspring of mothers who slept after midnight had a higher risk of night waking for > 1 h (RR = 1.38, 95% CI 1.30–1.47), sleeping for < 8 h at night (RR = 1.31, 95% CI 1.22–1.40), and falling asleep at 22:00 or later (RR = 1.53, 95% CI 1.48–1.58).

In the sub-analysis limited to participants who slept for 7–9 h during pregnancy, we found similar associations between maternal sleep before pregnancy and the offspring's sleep outcome (Supplemental Table 2). Maternal sleep for < 6 h during pregnancy was associated with a higher risk of some sleep outcomes. Infants whose mothers slept for less than 6 h during pregnancy tended to be awake for > 1 h at night (RR = 1.53, 95% CI 1.35–1.72), to sleep for < 8 h during night (RR = 1.66, 95% CI 1.48–1.88), and to sleep at 22:00 or later (RR = 1.39, 95% CI 1.31–1.47), compared to the infants whose mother slept for 7–8 h. On the contrary, compared to the offspring of mothers who slept for 7–8 h, offspring of mothers who slept for more than 10 h during pregnancy were also at a higher risk of night waking for > 1 h (RR = 1.25, 95% CI 1.09–1.44) and sleeping for < 8 h at night (RR = 1.26, 95% CI 1.09–1.46). Compared to offspring of mothers who slept before midnight before pregnancy, offspring of mothers who slept after midnight had a higher risk of night waking for > 1 h (RR = 1.38, 95% CI 1.30–1.47), sleeping for < 8 h at night (RR = 1.31, 95% CI 1.22–1.40), and falling asleep at 22:00 or later (RR = 1.53, 95% CI 1.48–1.58).

Maternal sleep during pregnancy and infant sleep (Table 3). As for the analysis of maternal sleep before pregnancy, short or long sleep duration and sleeping after midnight during pregnancy were associated with a higher risk of some sleep outcomes. Infants whose mothers slept for less than 6 h during pregnancy tended to be awake for > 1 h at night (RR = 1.53, 95% CI 1.35–1.72), to sleep for < 8 h during night (RR = 1.66, 95% CI 1.48–1.88), and to sleep at 22:00 or later (RR = 1.39, 95% CI 1.31–1.47), compared to the infants whose mother slept for 7–8 h. On the contrary, compared to the offspring of mothers who slept for 7–8 h, offspring of mothers who slept for more than 10 h during pregnancy tended to sleep at 22:00 or later (RR = 1.08, 95% CI 1.02–1.15). Maternal bedtime after midnight during pregnancy was also associated with a higher risk of infants night waking for > 1 h (RR = 1.41, 95% CI 1.32–1.51), sleeping for < 8 h at night (RR = 1.41, 95% CI 1.32–1.51), falling asleep at 22:00 or later (RR = 1.58, 95% CI 1.53–1.63), and frequency of crying (RR = 1.08, 95% CI 1.02–1.15), compared to the group of maternal bedtime after midnight.

In the sub-analysis limited to the participants who slept for 7–9 h before pregnancy, we found similar associations between maternal sleep during pregnancy and infants' sleep outcome (Supplemental Table 2). Maternal sleep for less than 6 h and for more than 10 h increased the risk ratio of falling asleep at 22:00 or after. Maternal bedtime after midnight increased the risk ratio of infants awakening > 1 h at night, sleeping < 8 h, and falling asleep at 22:00 or later.

Subjective items of sleep during pregnancy were also associated with the offspring's sleeping problems. For example, maternal “very light” sleep was associated with a higher risk of 3 or more waking instances in a night (RR = 1.74, 95% CI 1.47–2.06), night waking for more than 1 h (RR = 1.24, 95% CI 1.11–1.39), sleeping for less than 8 h at night (RR = 1.38, 95% CI 1.23–1.53), sleeping at 22:00 or later (RR = 1.08, 95% CI 1.02–1.15), crying 5 days or more in a week (RR = 1.52, 95% CI 1.38–1.67), compared to the group of maternal “normal” sleep depth.

Maternal sleep and offspring developmental progress. We used the Japanese version of the Ages and Stages Questionnaire, third edition (J-ASQ-3), to evaluate the offspring's development. There were no associations between sleep duration or bedtime, both before and during pregnancy, and abnormal J-ASQ-3 scores (Table 4). However, “good” and “very good” feelings when waking up during pregnancy were associated with a lower risk of abnormal J-ASQ-3 scores for any one of the five domains in a multivariable model (RR for good vs. normal = 0.86, 95% CI 0.81–0.91; RR for very good feeling vs. normal = 0.81, 95% CI 0.69–0.95) (Table 5), compared to the group of maternal “normal” feelings at waking up. Moreover, for the depth of sleep during pregnancy, “very deep” sleep decreased the risk of abnormal J-ASQ-3 scores (RR for very deep vs. normal = 0.83, 95% CI 0.71–0.98), compared to the group of maternal “normal” sleep depth.

Table 2. Association between sleep before pregnancy and infant sleep, Japan Environment and Children's Study (2011–2014). CI confidence interval, RR risk ratio. Bold fonts showed the items of infant's sleep outcomes. *Adjusted for maternal age at delivery, smoking habits, alcohol consumption, pre-pregnancy body mass index, gestational age at birth, parity, infertility treatment, and infant sex.
| No. of participants | Maternal age adjusted model | Multivariable model\(^a\) |
|---------------------|-----------------------------|---------------------------|
|                     | % RR 95% CI                  | RR 95% CI                 |

### > 3 nighttime waking instances

#### Sleep duration

| Nighttime waking instances | <6 h | 6-7 | 7-8 | 8-9 | 9-10 | 10+ |
|---------------------------|------|-----|-----|-----|------|-----|
| No. of participants       | 3540 | 11,099 | 23,050 | 21,043 | 10,394 | 4701 |
| RR 95% CI                 | 2.3 | 0.97 | 0.77 | 1.22 | 1.00 | 0.79 |
| RR 95% CI                 | 1.26 | 0.94 | 0.81 | 1.09 |     |     |

#### Bedtime

| Bedtime | 21 < 24 | 24 < 27 | Other |
|---------|---------|---------|-------|
| No. of participants | 54,403 | 17,798 | 1626 |
| RR 95% CI | 2.5 | Ref | Ref |
| RR 95% CI | 1.40 |     |     |

#### Depth of sleep

| Depth of sleep | Very light | Light | Normal | Deep | Very deep |
|----------------|------------|-------|--------|------|-----------|
| No. of participants | 5054 | 30,977 | 29,459 | 7007 | 1330 |
| RR 95% CI | 3.4 | 2.9 | 2.0 | 1.7 | 1.4 |
| RR 95% CI | 1.73 | 1.45 | 1.05 | 0.85 | 0.74 |

#### Feeling when waking up in the morning

| Feeling when waking up in the morning | Very bad | Bad | Normal | Good | Very good |
|--------------------------------------|----------|-----|--------|------|-----------|
| No. of participants | 1112 | 15,106 | 45,965 | 10,314 | 1330 |
| RR 95% CI | 3.4 | 2.8 | 2.4 | 1.8 | 2.0 |
| RR 95% CI | 1.50 | 1.19 | 1.10 | 0.74 | 0.81 |

### > 1 waking instances lasting > 1 h

#### Sleep duration

| Waking instances lasting > 1 h | <6 h | 6-7 | 7-8 | 8-9 | 9-10 | 10+ |
|------------------------------|------|-----|-----|-----|------|-----|
| No. of participants | 3540 | 11,099 | 23,050 | 21,043 | 10,394 | 4701 |
| RR 95% CI | 2.5 | 0.93 | 0.80 | 1.08 | 0.94 | 0.81 |
| RR 95% CI | 1.09 |     |     |     |     |     |

#### Bedtime

| Bedtime | 21 < 24 | 24 < 27 | Other |
|---------|---------|---------|-------|
| No. of participants | 54,403 | 17,798 | 1626 |
| RR 95% CI | 2.5 | Ref | Ref |
| RR 95% CI | 1.40 |     |     |

#### Depth of sleep

| Depth of sleep | Very light | Light | Normal | Deep | Very deep |
|----------------|------------|-------|--------|------|-----------|
| No. of participants | 5054 | 30,977 | 29,459 | 7007 | 1330 |
| RR 95% CI | 3.4 | 2.9 | 2.0 | 1.7 | 1.4 |
| RR 95% CI | 1.73 | 1.45 | 1.05 | 0.85 | 0.74 |

#### Feeling when waking up in the morning

| Feeling when waking up in the morning | Very bad | Bad | Normal | Good | Very good |
|--------------------------------------|----------|-----|--------|------|-----------|
| No. of participants | 1112 | 15,106 | 45,965 | 10,314 | 1330 |
| RR 95% CI | 3.4 | 2.8 | 2.4 | 1.8 | 2.0 |
| RR 95% CI | 1.50 | 1.19 | 1.10 | 0.74 | 0.81 |

### < 8 h of sleep during the night (20:00–7:59)

#### Sleep duration

| Sleep duration | <6 h | 6-7 | 7-8 | 8-9 | 9-10 |
|----------------|------|-----|-----|-----|------|
| No. of participants | 3540 | 11,099 | 23,050 | 21,043 | 10,394 |
| RR 95% CI | 2.5 | 0.93 | 0.80 | 1.08 | 0.94 |
| RR 95% CI | 1.09 |     |     |     |     |

Continued
|                          | No. of participants | No. of outcome | Maternal age adjusted model | Multivariable model |
|--------------------------|---------------------|----------------|-----------------------------|--------------------|
|                          |                     | %  | RR   | 95% CI   | RR   | 95% CI   |                  |
| 10<                      | 4701                | 245 | 5.2  | 1.00 | 0.87 | 1.14 | 1.01 | 0.88 | 1.16 |
| Bedtime                  |                     |    |      |      |      |      |      |      |      |
| 21<24                    | 54,403              | 2508 | 4.6  | Ref | Ref |      |      |      |      |
| 24<27                    | 17,798              | 1205 | 6.8  | 1.47 | 1.38 | 1.57 | 1.41 | 1.32 | 1.51 |
| Other                    | 1626                | 130  | 8.0  | 1.72 | 1.45 | 2.03 | 1.69 | 1.43 | 2.01 |
| Depth of sleep           |                     |    |      |      |      |      |      |      |      |
| Very light               | 5054                | 349  | 6.9  | 1.36 | 1.22 | 1.52 | 1.38 | 1.23 | 1.55 |
| Light                    | 30,977              | 1640 | 5.3  | 1.05 | 0.98 | 1.13 | 1.07 | 1.00 | 1.14 |
| Normal                   | 29,459              | 1477 | 5.0  | Ref | Ref |      |      |      |      |
| Deep                     | 7007                | 516  | 4.5  | 0.90 | 0.80 | 1.02 | 0.89 | 0.79 | 1.00 |
| Very deep                | 1330                | 61   | 4.6  | 0.91 | 0.71 | 1.17 | 0.90 | 0.70 | 1.15 |
| Feeling when waking up in the morning |     |    |      |      |      |      |      |      |      |
| Very bad                 | 1112                | 92   | 8.3  | 1.63 | 1.34 | 2.00 | 1.62 | 1.33 | 1.98 |
| Bad                      | 15,106              | 934  | 6.2  | 1.25 | 1.16 | 1.34 | 1.25 | 1.16 | 1.34 |
| Normal                   | 45,965              | 2284 | 5.0  | Ref | Ref |      |      |      |      |
| Good                     | 10,314              | 477  | 4.6  | 0.93 | 0.85 | 1.03 | 0.93 | 0.84 | 1.02 |
| Very good                | 1330                | 56   | 4.2  | 0.84 | 0.65 | 1.09 | 0.83 | 0.64 | 1.08 |
| Falling asleep at 22:00 or later |     |    |      |      |      |      |      |      |      |
| Sleep duration           |                     |    |      |      |      |      |      |      |      |
| <6h                      | 3540                | 1029 | 29.1 | 1.43 | 1.35 | 1.51 | 1.39 | 1.31 | 1.47 |
| 6<7                      | 11,099              | 2682 | 24.2 | 1.20 | 1.15 | 1.25 | 1.18 | 1.13 | 1.23 |
| 7<8                      | 23,050              | 4617 | 20.0 | Ref | Ref |      |      |      |      |
| 8<9                      | 21,043              | 3720 | 17.7 | 0.88 | 0.85 | 0.92 | 0.90 | 0.87 | 0.94 |
| 9<10                     | 10,394              | 1740 | 16.7 | 0.83 | 0.79 | 0.87 | 0.86 | 0.82 | 0.91 |
| 10<                      | 4701                | 1054 | 22.4 | 1.07 | 1.01 | 1.14 | 1.08 | 1.02 | 1.15 |
| Bedtime                  |                     |    |      |      |      |      |      |      |      |
| 21<24                    | 54,403              | 9402 | 17.3 | Ref | Ref |      |      |      |      |
| 24<27                    | 17,798              | 5120 | 28.8 | 1.65 | 1.60 | 1.70 | 1.58 | 1.53 | 1.63 |
| Other                    | 1626                | 320  | 19.7 | 1.12 | 1.01 | 1.24 | 1.10 | 0.99 | 1.21 |
| Depth of sleep           |                     |    |      |      |      |      |      |      |      |
| Very light               | 5054                | 1087 | 21.5 | 1.07 | 1.01 | 1.14 | 1.08 | 1.02 | 1.15 |
| Light                    | 30,977              | 6213 | 20.1 | 1.01 | 0.98 | 1.04 | 1.02 | 0.99 | 1.05 |
| Normal                   | 29,459              | 5882 | 20.0 | Ref | Ref |      |      |      |      |
| Deep                     | 7007                | 1404 | 20.0 | 1.00 | 0.95 | 1.06 | 0.99 | 0.94 | 1.04 |
| Very deep                | 1330                | 256  | 19.3 | 0.95 | 0.85 | 1.06 | 0.93 | 0.84 | 1.04 |
| Feeling when waking up in the morning |     |    |      |      |      |      |      |      |      |
| Very bad                 | 1112                | 268  | 24.1 | 1.16 | 1.04 | 1.29 | 1.14 | 1.03 | 1.27 |
| Bad                      | 15,106              | 3341 | 22.1 | 1.10 | 1.06 | 1.14 | 1.10 | 1.06 | 1.14 |
| Normal                   | 45,965              | 9215 | 20.1 | Ref | Ref |      |      |      |      |
| Good                     | 10,314              | 1804 | 17.5 | 0.88 | 0.84 | 0.92 | 0.88 | 0.84 | 0.92 |
| Very good                | 1330                | 214  | 16.1 | 0.80 | 0.71 | 0.91 | 0.80 | 0.70 | 0.90 |
| Frequency of crying at night (≥5 days/week) |     |    |      |      |      |      |      |      |      |
| Sleep duration           |                     |    |      |      |      |      |      |      |      |
| <6h                      | 3540                | 256  | 7.2  | 0.99 | 0.88 | 1.13 | 1.01 | 0.89 | 1.14 |
| 6<7                      | 11,099              | 848  | 7.6  | 1.04 | 0.96 | 1.13 | 1.05 | 0.97 | 1.13 |
| 7<8                      | 23,050              | 1695 | 7.4  | Ref | Ref |      |      |      |      |
| 8<9                      | 21,043              | 1480 | 7.0  | 0.96 | 0.89 | 1.02 | 0.96 | 0.90 | 1.03 |
| 9<10                     | 10,394              | 761  | 7.3  | 1.00 | 0.92 | 1.09 | 1.00 | 0.92 | 1.09 |
| 10<                      | 4701                | 307  | 6.5  | 0.91 | 0.81 | 1.02 | 0.92 | 0.82 | 1.04 |
| Bedtime                  |                     |    |      |      |      |      |      |      |      |
| 21<24                    | 54,403              | 3881 | 7.1  | Ref | Ref |      |      |      |      |
| 24<27                    | 17,798              | 1351 | 7.6  | 1.07 | 1.01 | 1.14 | 1.08 | 1.02 | 1.15 |
| Other                    | 1626                | 115  | 7.1  | 1.01 | 0.85 | 1.21 | 1.04 | 0.87 | 1.24 |
| Depth of sleep           |                     |    |      |      |      |      |      |      |      |
| Very light               | 5054                | 482  | 9.5  | 1.50 | 1.36 | 1.65 | 1.52 | 1.38 | 1.67 |
ASQ scores. Subjective light sleep and bad mood upon waking may reflect maternal SDB or depression and infant sleeping problems may be influenced via life rhythm after childbirth. SDB and maternal depression increase inflammatory cytokine levels; maternal inflammation during pregnancy was associated with the offspring’s outcomes. In addition, maternal subjective deep sleep and good mood at waking up during pregnancy were inversely associated with the infants’ sleep problems and the J-ASQ abnormal scores.

In this study, the participants tended to sleep longer and go to bed earlier during pregnancy than they did before pregnancy. In Japan, many women still stop working due to pregnancy or take maternity leave during late pregnancy. For that reason, sleep duration and bedtime might improve during pregnancy.

Sleep cycle develops from the fetal period. Animal studies have shown that the circadian rhythm is affected by maternal life rhythms via endogenous substances such as melatonin. Animal studies have also reported that exposure to sleep deprivation or artificial disappearance of light–dark cycle during pregnancy affects the offspring’s circadian rhythm abnormality and abnormal behavioral pattern. In this study, mother’s short sleep and late bedtime were associated with the offspring’s sleeping problems, in part, because of the influence of maternal life rhythm during the fetal period.

In this study, the participants tended to sleep longer and go to bed earlier during pregnancy than they did before pregnancy. In Japan, many women still stop working due to pregnancy or take maternity leave during late pregnancy. For that reason, sleep duration and bedtime might improve during pregnancy.

In addition, it is considered that postpartum sleep pattern would partly correlate with sleep pattern before or during pregnancy. The study of 18-month-old twin infants reported that the genetic effect on sleep duration was 30.8% and the environmental effect was 64.1%. The association between sleep before or during pregnancy and infant sleeping problems may improve subjective sleep quality and subsequent offspring abnormal scores.

Subjective sleep quality was associated not only with infants’ sleep problem but also with the risk of abnormal ASQ scores. Subjective light sleep and bad mood upon waking may reflect maternal SDB or depression. Furthermore, it has been reported that both of these factors are related to the offspring’s development. One potential factor explaining the association between maternal sleep and the offspring’s outcomes is inflammation. SDB and maternal depression increase inflammatory cytokine levels; maternal inflammation during pregnancy can cause developmental disorders. In addition, maternal SDB may affect the offspring’s development via low birth weight, which has been reported to be associated with neurodevelopment. Interventions in maternal SDB and depression during pregnancy may improve subjective sleep quality and subsequent offspring sleep and development.

We have previously reported that maternal sleep habits, such as short sleep and late bedtime, before and during pregnancy, increased the risk ratio of long sleep duration during the day, bad mood, frequency of crying, for a long time, and intense crying in 1-month-old offspring. We further showed the association between maternal unsuitable sleep habits and the offspring’s non-desirable sleep habits as lasting even 1 year after birth. It is expected that children’s sleep and development will be influenced more by factors after birth than by prenatal ones. Therefore, it is important to clarify how long maternal sleep habits both before and during pregnancy are related to offspring’s sleep and development progression and to verify whether an intervention of maternal sleep, at any time point, improves offspring’s sleep and developmental outcomes.

This study was not without limitations. Because the present study was an observational study, confounding factors, such as parental life rhythm, that were not part of our evaluations might have been present. Moreover, information regarding both maternal sleep habits and infant’s outcomes was collected using a self-reported questionnaire, and thus, it had a risk of bias, such as a recall bias. The questions about maternal and infant sleep have not been previously validated. For example, we used the frequency of infant’s night crying as outcome, but we could not get the intended information about the duration and reason for the infant crying. Thus, there could

### Table 3. Association between sleep during pregnancy and infant sleep, Japan Environment and Children’s Study (2011–2014).

| Feeling when waking up in the morning | No. of participants | Maternal age adjusted model | Multivariable modela |
|--------------------------------------|---------------------|-----------------------------|----------------------|
|                                      | No. of outcome      | %   | RR   | 95% CI  | RR   | 95% CI  |
| Light                                | 30,977              | 2470 | 8.0  | 1.25   | 1.18   | 1.32   | 1.25   | 1.18   | 1.32   |
| Normal                               | 29,459              | 1882 | 6.4  | Ref    | Ref    | Ref    |
| Deep                                 | 7007                | 431  | 6.2  | 0.96   | 0.87   | 1.07   | 0.96   | 0.87   | 1.06   |
| Very deep                            | 1330                | 82   | 6.2  | 0.97   | 0.78   | 1.20   | 0.97   | 0.79   | 1.20   |
| Good                                 | 10,314              | 596  | 5.8  | 0.81   | 0.74   | 0.88   | 0.80   | 0.74   | 0.87   |
| Very good                            | 1330                | 71   | 5.3  | 0.75   | 0.60   | 0.94   | 0.75   | 0.60   | 0.95   |

Feeling when waking up in the morning: Very good, Good, Normal, Light, Deep, Very bad, Bad, Normal, Light.

The present study showed that maternal short or long sleep and bedtime after midnight, both before and during pregnancy, increased the risk ratio of the offspring’s sleeping problems at 1 year of age. The sub-analysis limited to participants with adequate sleep durations showed that maternal sleep pattern both before and during pregnancy was associated with the infants’ sleep outcomes. In addition, maternal subjective deep sleep and good mood at waking up during pregnancy were inversely associated with the infants’ sleep problems and the J-ASQ abnormal scores.

### Discussion

This study investigated whether maternal sleep before and during pregnancy was associated with sleeping or developmental problems in 1-year-old infants, using data from a nationwide large-scale cohort study in Japan. The present study showed that maternal short or long sleep and bedtime after midnight, both before and during pregnancy, increased the risk ratio of the offspring’s sleeping problems at 1 year of age. The association between sleep before or during pregnancy and infant sleep, at any time point, improves offspring’s sleep and developmental outcomes.

Bold fonts showed the items of infant’s sleep outcomes. Adjusted for maternal age at delivery, smoking habits, alcohol consumption, pre-pregnancy body mass index, gestational age at birth, parity, infertility treatment, and infant sex.

Feeling when waking up in the morning: Very good, Good, Normal, Light, Deep, Very bad, Bad, Normal, Light.
| No. of participants | No. of outcome | Maternal age adjusted model | Multivariable model* |
|---------------------|---------------|-----------------------------|---------------------|
|                     |               | %  | RR  | 95% CI | RR  | 95% CI |

### Communication

**Sleep duration**

| <6 h | 4489 | 5  | 0.1 | 1.19 | 0.45 | 3.15 | 1.15 | 0.43 | 3.03 |
| 6-7  | 13,427 | 18 | 0.1 | 1.40 | 0.75 | 2.61 | 1.32 | 0.71 | 2.47 |
| 7-8  | 23,058 | 22 | 0.1 | Ref | Ref |      |      |      |      |
| 8-9  | 16,779 | 13 | 0.1 | 0.82 | 0.41 | 1.63 | 0.90 | 0.45 | 1.80 |
| 9-10 | 6863  | 6  | 0.1 | 0.95 | 0.39 | 2.35 | 1.12 | 0.45 | 2.82 |
| 10+  | 2975  | 3  | 0.1 | 1.29 | 0.38 | 4.31 | 1.42 | 0.42 | 4.78 |

**Bedtime**

| 21-24 | 45,971 | 46 | 0.1 | Ref | Ref |      |      |      |      |
| 24-27 | 19,816 | 19 | 0.1 | 1.01 | 0.59 | 1.73 | 0.86 | 0.49 | 1.50 |
| Other | 1804   | 2  | 0.1 | 1.33 | 0.32 | 5.51 | 1.39 | 0.33 | 5.79 |

### Gross motor skills

**Sleep duration**

| <6 h | 4489 | 265 | 5.9 | 1.08 | 0.95 | 1.23 | 1.07 | 0.94 | 1.22 |
| 6-7  | 13,427 | 832 | 6.2 | 1.12 | 1.03 | 1.22 | 1.11 | 1.02 | 1.20 |
| 7-8  | 23,066 | 1264 | 5.5 | Ref | Ref |      |      |      |      |
| 8-9  | 16,775 | 902 | 5.4 | 0.99 | 0.91 | 1.07 | 1.02 | 0.93 | 1.10 |
| 9-10 | 6861  | 327 | 4.8 | 0.89 | 0.79 | 1.01 | 0.94 | 0.84 | 1.06 |
| 10+  | 2975  | 120 | 4.0 | 0.82 | 0.69 | 0.99 | 0.86 | 0.72 | 1.03 |

**Bedtime**

| 21-24 | 45,972 | 2546 | 5.5 | Ref | Ref |      |      |      |      |
| 24-27 | 19,816 | 1073 | 5.4 | 1.01 | 0.95 | 1.09 | 0.97 | 0.90 | 1.05 |
| Other | 1805   | 91  | 5.0 | 1.01 | 0.83 | 1.24 | 1.06 | 0.86 | 1.30 |

### Fine motor skills

**Sleep duration**

| <6 h | 4489 | 252 | 5.6 | 1.01 | 0.88 | 1.15 | 1.02 | 0.90 | 1.17 |
| 6-7  | 13,415 | 781 | 5.8 | 1.04 | 0.95 | 1.13 | 1.05 | 0.97 | 1.15 |
| 7-8  | 23,063 | 1283 | 5.6 | Ref | Ref |      |      |      |      |
| 8-9  | 16,766 | 932 | 5.6 | 1.01 | 0.93 | 1.09 | 0.99 | 0.91 | 1.08 |
| 9-10 | 6859  | 373 | 5.4 | 1.00 | 0.90 | 1.12 | 0.98 | 0.87 | 1.09 |
| 10+  | 2974  | 141 | 4.7 | 0.95 | 0.80 | 1.12 | 0.93 | 0.79 | 1.10 |

**Bedtime**

| 21-24 | 45,951 | 2623 | 5.7 | Ref | Ref |      |      |      |      |
| 24-27 | 19,811 | 1053 | 5.3 | 0.96 | 0.90 | 1.03 | 1.00 | 0.93 | 1.07 |
| Other | 1804   | 86  | 4.8 | 0.92 | 0.74 | 1.13 | 0.94 | 0.76 | 1.16 |

### Problems solving

**Sleep duration**

| <6 h | 4482 | 246 | 5.5 | 1.09 | 0.95 | 1.25 | 1.06 | 0.93 | 1.21 |
| 6-7  | 13,404 | 726 | 5.4 | 1.08 | 0.98 | 1.18 | 1.04 | 0.95 | 1.14 |
| 7-8  | 23,041 | 1151 | 5.0 | Ref | Ref |      |      |      |      |
| 8-9  | 16,757 | 831 | 5.0 | 1.00 | 0.92 | 1.09 | 1.05 | 0.96 | 1.15 |
| 9-10 | 6848  | 343 | 5.0 | 1.03 | 0.91 | 1.16 | 1.12 | 1.00 | 1.26 |
| 10+  | 2973  | 141 | 4.7 | 1.04 | 0.88 | 1.24 | 1.10 | 0.93 | 1.31 |

**Bedtime**

| 21-24 | 45,918 | 2321 | 5.1 | Ref | Ref |      |      |      |      |
| 24-27 | 19,785 | 1042 | 5.3 | 1.08 | 1.00 | 1.16 | 1.00 | 0.93 | 1.08 |
| Other | 1802   | 75  | 4.2 | 0.89 | 0.71 | 1.12 | 0.90 | 0.72 | 1.13 |

### Personal-social characteristics

**Sleep duration**

| <6 h | 4480 | 50  | 1.1 | 1.11 | 0.82 | 1.51 | 1.20 | 0.88 | 1.62 |
| 6-7  | 13,402 | 142 | 1.1 | 1.05 | 0.85 | 1.29 | 1.12 | 0.91 | 1.37 |
| 7-8  | 23,017 | 231 | 1.0 | Ref | Ref |      |      |      |      |
| 8-9  | 16,731 | 222 | 1.3 | 1.33 | 1.11 | 1.60 | 1.23 | 1.02 | 1.48 |
| 9-10 | 6852  | 99  | 1.4 | 1.48 | 1.17 | 1.87 | 1.30 | 1.03 | 1.65 |

Continued
The baseline profiles of participants of the JECS have been reported previously. Participants answered a questionnaire about their offspring 1 year after delivery (C-1y). Participants also answered a questionnaire about their offspring 1 year after delivery (C-1y). The data used in this study were obtained from the JECS, an ongoing large-scale cohort study. The JECS elucidated environmental factors that are associated with children's health and development, and was designed to follow women through their pregnancy until their newborns grow up to be 13 years old. The participants were recruited between 2011 and 2014 from 15 regions throughout Japan, and the follow-up was mainly conducted via a self-administered questionnaire. The detailed protocol has been reported elsewhere.

Table 4. Association between sleep before pregnancy and infant development, Japan Environment and Children's Study (2011–2014). CI confidence interval, RR risk ratio. Bold fonts showed the items of the Ages and Stages Questionnaire. *Adjusted for maternal age at delivery, smoking habits, alcohol consumption, prepregnancy body mass index, gestational age at birth, parity, infertility treatment, and infant sex.

| Sleep duration | No. of participants | Maternal age adjusted model | Multivariable model* |
|----------------|---------------------|-----------------------------|----------------------|
|                |                     | % RR 95% CI                  | RR 95% CI            |
| < 6 h          | 4491                | 621 13.8 1.01 0.94 1.10 1.01 0.93 1.09 |
| 6 ≤ 7          | 13,432              | 1917 14.3 1.04 0.99 1.10 1.05 0.98 1.08 |
| 7 < 8          | 23,070              | 3146 13.6 Ref Ref            | Ref                  |
| 8 ≤ 9          | 16,783              | 2218 13.2 0.98 0.93 1.03 0.99 0.95 1.05 |
| 9 ≤ 10         | 6865                | 874 12.7 0.96 0.89 1.03 0.99 0.92 1.06 |
| 10 ≤ 29        | 2976                | 365 12.3 1.00 0.90 1.10 1.02 0.92 1.13 |

Methods

**Research ethics.** The study protocol was approved by the Ministry of Environment’s Institutional Review Board on Epidemiological Studies and by the Ethics Committee of all participating institutions: the National Institute for Environmental Studies that leads the Japan Environment and Children's Study (JECS), the National Center for Child Health and Development, Hokkaido University, Sapporo Medical University, Ashikawa Medical College, Japanese Red Cross Hokkaido College of Nursing, Tohoku University, Fukushima Medical University, Chiba University, Yokohama City University, University of Yamanashi, Shinshu University, University of Toyama, Nagoya City University, Kyoto University, Doshisha University, Osaka University, Osaka Medical Center and Research Institute for Maternal and Child Health, Hyogo College of Medicine, Tottori University, Kochi University, University of Occupational and Environmental Health, Kyushu University, Kumamoto University, University of Miyazaki, and University of Ryukyu. Written informed consent was obtained from all participants. All methods were performed in accordance with the approved guidelines.

**Study participants.** The data used in this study were obtained from the JECS, an ongoing large-scale cohort study. The JECS elucidated environmental factors that are associated with children's health and development, and was designed to follow women through their pregnancy until their newborns grow up to be 13 years old. The participants were recruited between 2011 and 2014 from 15 regions throughout Japan, and the follow-up was mainly conducted via a self-administered questionnaire. The detailed protocol has been reported elsewhere.

The baseline profiles of participants of the JECS have been reported previously. Participants answered a questionnaire about lifestyle and behavior twice during pregnancy. The questionnaire answered at recruitment was designed to follow women through their pregnancy until their newborns grow up to be 13 years old. The participants were recruited between 2011 and 2014 from 15 regions throughout Japan, and the follow-up was mainly conducted via a self-administered questionnaire. The detailed protocol has been reported elsewhere.

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| Communication                  | No. of participants | No. of outcome | Maternal age adjusted model | Multivariable model<sup>a</sup> |
|--------------------------------|---------------------|---------------|----------------------------|---------------------------------|
|                                |                     | %             | RR     | 95% CI | RR     | 95% CI |
| Sleep duration                 |                     |               |        |        |        |        |
| < 6 h                          | 3186                | 5             | 0.2    | 1.32   | 0.51   | 3.43   | 1.29   | 0.49   | 3.35   |
| 6 < 7                          | 10,130              | 12            | 0.1    | 0.97   | 0.49   | 1.93   | 0.93   | 0.47   | 1.86   |
| 7 < 8                          | 21,181              | 26            | 0.1    | 0.55   | 0.28   | 1.07   | 0.60   | 0.30   | 1.16   |
| 8 < 9                          | 19,275              | 13            | 0.1    | 0.88   | 0.42   | 1.83   | 0.99   | 0.47   | 2.08   |
| > 9                            | 4291                | 1             | 0.0    | 0.37   | 0.03   | 1.65   | 0.24   | 0.03   | 1.80   |
| Bedtime                        |                     |               |        |        |        |        |
| 21 < 24                        | 50,034              | 48            | 0.1    | Ref    | Ref    |        |        |
| 24 < 27                        | 16,083              | 18            | 0.1    | 1.23   | 0.72   | 2.12   | 1.07   | 0.61   | 1.86   |
| Other                          | 1474                | 1             | 0.1    | 0.78   | 0.11   | 5.64   | 0.82   | 0.11   | 5.95   |
| Depth of sleep                 |                     |               |        |        |        |        |
| Very light                     | 4563                | 4             | 0.1    | 0.81   | 0.28   | 2.30   | 0.82   | 0.29   | 2.35   |
| Light                          | 28,285              | 24            | 0.1    | 0.78   | 0.45   | 1.33   | 0.79   | 0.46   | 1.35   |
| Normal                         | 27,044              | 29            | 0.1    | Ref    | Ref    |        |        |
| Deep                           | 6465                | 6             | 0.1    | 0.88   | 0.37   | 2.12   | 0.86   | 0.36   | 2.06   |
| Very deep                      | 1234                | 4             | 0.3    | 3.16   | 1.11   | 8.98   | 3.01   | 1.06   | 8.55   |
| Feeling when waking up in the morning |               |               |        |        |        |        |
| Very bad                       | 991                 | 3             | 0.3    | 3.41   | 1.06   | 10.99  | 3.38   | 1.05   | 10.88  |
| Bad                            | 13,634              | 15            | 0.1    | 1.13   | 0.63   | 2.04   | 1.12   | 0.62   | 2.02   |
| Normal                         | 42,197              | 42            | 0.1    | Ref    | Ref    |        |        |
| Good                           | 9530                | 4             | 0.0    | 0.41   | 0.15   | 1.16   | 0.40   | 0.14   | 1.11   |
| Very good                      | 1239                | 3             | 0.2    | 2.41   | 0.75   | 7.75   | 2.27   | 0.70   | 7.33   |
| Gross motor skills             |                     |               |        |        |        |        |
| Sleep duration                 |                     |               |        |        |        |        |
| < 6 h                          | 3186                | 191           | 6.0    | 1.06   | 0.92   | 1.23   | 1.06   | 0.92   | 1.23   |
| 6 < 7                          | 10,130              | 613           | 6.1    | 1.06   | 0.97   | 1.17   | 1.05   | 0.95   | 1.15   |
| 7 < 8                          | 21,184              | 1203          | 5.7    | Ref    | Ref    |        |        |
| 8 < 9                          | 19,275              | 1020          | 5.3    | 0.94   | 0.86   | 1.02   | 0.96   | 0.89   | 1.04   |
| 9 < 10                         | 9526                | 497           | 5.2    | 0.94   | 0.85   | 1.04   | 0.99   | 0.89   | 1.09   |
| 10 <                          | 4292                | 186           | 4.3    | 0.85   | 0.73   | 0.99   | 0.88   | 0.76   | 1.03   |
| Bedtime                        |                     |               |        |        |        |        |
| 21 < 24                        | 50,037              | 2778          | 5.6    | Ref    | Ref    |        |        |
| 24 < 27                        | 16,079              | 842           | 5.2    | 0.98   | 0.91   | 1.05   | 0.93   | 0.86   | 1.01   |
| Other                          | 1477                | 90            | 6.1    | 1.16   | 0.95   | 1.43   | 1.19   | 0.97   | 1.46   |
| Depth of sleep                 |                     |               |        |        |        |        |
| Very light                     | 4564                | 258           | 5.7    | 1.00   | 0.88   | 1.13   | 1.02   | 0.90   | 1.16   |
| Light                          | 28,288              | 1521          | 5.4    | 0.95   | 0.89   | 1.02   | 0.96   | 0.89   | 1.03   |
| Normal                         | 27,045              | 1512          | 5.6    | Ref    | Ref    |        |        |
| Deep                           | 6463                | 355           | 5.5    | 0.99   | 0.89   | 1.11   | 0.99   | 0.88   | 1.10   |
| Very deep                      | 1233                | 64            | 5.2    | 0.95   | 0.75   | 1.21   | 0.96   | 0.75   | 1.22   |
| Feeling when waking up in the morning |               |               |        |        |        |        |
| Very bad                       | 991                 | 48            | 4.8    | 0.95   | 0.72   | 1.25   | 0.97   | 0.73   | 1.28   |
| Bad                            | 13,636              | 762           | 5.6    | 1.04   | 0.96   | 1.13   | 1.05   | 0.97   | 1.13   |
| Normal                         | 42,197              | 2306          | 5.5    | Ref    | Ref    |        |        |
| Good                           | 9531                | 529           | 5.6    | 1.00   | 0.92   | 1.10   | 1.00   | 0.91   | 1.09   |
| Very good                      | 1238                | 65            | 5.3    | 0.95   | 0.75   | 1.21   | 0.93   | 0.73   | 1.17   |
| Fine motor skills              |                     |               |        |        |        |        |
| Sleep duration                 |                     |               |        |        |        |        |
| < 6 h                          | 3184                | 180           | 5.7    | 1.00   | 0.85   | 1.16   | 1.00   | 0.86   | 1.16   |
| 6 < 7                          | 10,124              | 587           | 5.8    | 1.01   | 0.92   | 1.11   | 1.03   | 0.93   | 1.13   |
| 7 < 8                          | 21,178              | 1210          | 5.7    | Ref    | Ref    |        |        |
| 8 < 9                          | 19,265              | 1068          | 5.5    | 0.97   | 0.90   | 1.06   | 0.96   | 0.89   | 1.04   |
| 9 < 10                         | 9524                | 492           | 5.2    | 0.93   | 0.84   | 1.02   | 0.90   | 0.82   | 1.00   |
| Continued                      |                     |               |        |        |        |        |
|                        | No. of participants | No. of outcome | Maternal age adjusted model | Multivariable model<sup>a</sup> |
|------------------------|---------------------|----------------|----------------------------|---------------------------------|
|                        |                     | %              | RR 95% CI                   | RR 95% CI                       |
| No. of participants    |                     |                |                            |                                |
| 10< 4291               | 225                 | 5.2            | 1.01 0.88 1.16             | 1.01 0.88 1.16                 |
| Bedtime                |                     |                |                            |                                |
| 21 < 24 50,017         | 2841                | 5.7            | Ref                        | Ref                             |
| 24 < 27 16,674         | 838                 | 5.2            | 0.95 0.88 1.02             | 0.97 0.90 1.05                 |
| Other 1475             | 83                  | 5.6            | 1.04 0.84 1.29             | 1.05 0.85 1.29                 |
| Depth of sleep         |                     |                |                            |                                |
| Very light 4558        | 251                 | 5.5            | 0.96 0.84 1.09             | 0.94 0.82 1.06                 |
| Light 28,280           | 1577                | 5.6            | 0.97 0.91 1.04             | 0.97 0.90 1.04                 |
| Normal 27,035          | 1532                | 5.7            | Ref                        | Ref                             |
| Deep 6462             | 351                 | 5.4            | 0.97 0.87 1.08             | 0.98 0.88 1.10                 |
| Very deep 1231         | 51                  | 4.1            | 0.75 0.57 0.98             | 0.76 0.58 1.00                 |
| Feeling when waking up in the morning | |                |                            |                                |
| Very bad 990          | 58                  | 5.9            | 1.09 0.85 1.41             | 1.08 0.84 1.39                 |
| Bad 13,635            | 829                 | 6.1            | 1.09 1.01 1.17             | 1.08 1.00 1.17                 |
| Normal 42,175         | 2396                | 5.7            | Ref                        | Ref                             |
| Good 9528             | 425                 | 4.5            | 0.78 0.70 0.86             | 0.78 0.71 0.86                 |
| Very good 1238        | 54                  | 4.4            | 0.76 0.58 0.99             | 0.78 0.60 1.01                 |
| Problems solving      |                     |                |                            |                                |
| Sleep duration        |                     |                |                            |                                |
| <6 h 3182             | 182                 | 5.7            | 1.09 0.94 1.27             | 1.07 0.92 1.25                 |
| 6 < 7 10,115           | 525                 | 5.2            | 0.99 0.89 1.09             | 0.96 0.87 1.07                 |
| 7 < 8 21,161           | 1105                | 5.2            | Ref                        | Ref                             |
| 8 < 9 19,253          | 970                 | 5.0            | 0.97 0.89 1.05             | 1.01 0.93 1.10                 |
| 9 < 10 9508           | 438                 | 4.6            | 0.90 0.81 1.01             | 0.96 0.86 1.07                 |
| 10< 4286              | 218                 | 5.1            | 1.07 0.92 1.23             | 1.12 0.97 1.29                 |
| Bedtime               |                     |                |                            |                                |
| 21 < 24 49,976        | 2544                | 5.1            | Ref                        | Ref                             |
| 24 < 27 16,057        | 817                 | 5.1            | 1.03 0.96 1.11             | 0.96 0.89 1.04                 |
| Other 1472            | 77                  | 5.2            | 1.08 0.86 1.34             | 1.09 0.88 1.36                 |
| Depth of sleep        |                     |                |                            |                                |
| Very light 4557       | 211                 | 4.6            | 0.84 0.73 0.97             | 0.85 0.74 0.98                 |
| Light 28,256          | 1406                | 5.0            | 0.91 0.85 0.97             | 0.92 0.86 0.99                 |
| Normal 27,001         | 1463                | 5.4            | Ref                        | Ref                             |
| Deep 6458             | 312                 | 4.8            | 0.90 0.80 1.02             | 0.89 0.79 1.01                 |
| Very deep 1233        | 46                  | 3.7            | 0.70 0.53 0.94             | 0.70 0.53 0.93                 |
| Feeling when waking up in the morning | |                |                            |                                |
| Very bad 990          | 63                  | 6.4            | 1.28 1.01 1.64             | 1.29 1.01 1.64                 |
| Bad 13,620            | 737                 | 5.4            | 1.05 0.97 1.14             | 1.05 0.97 1.14                 |
| Normal 42,133         | 2204                | 5.2            | Ref                        | Ref                             |
| Good 9525             | 390                 | 4.1            | 0.77 0.70 0.86             | 0.77 0.69 0.85                 |
| Very good 1237        | 44                  | 3.6            | 0.67 0.50 0.90             | 0.66 0.50 0.89                 |
| Personal-social characteristics | |                |                            |                                |
| Sleep duration        |                     |                |                            |                                |
| <6 h 3182             | 40                  | 1.3            | 1.27 0.91 1.77             | 1.33 0.95 1.85                 |
| 6 < 7 10,110          | 105                 | 1.0            | 1.04 0.82 1.31             | 1.10 0.87 1.38                 |
| 7 < 8 21,141          | 211                 | 1.0            | Ref                        | Ref                             |
| 8 < 9 19,222          | 259                 | 1.4            | 1.36 1.13 1.63             | 1.27 1.06 1.53                 |
| 9 < 10 9511           | 112                 | 1.2            | 1.21 0.96 1.52             | 1.08 0.86 1.36                 |
| 10< 4287              | 51                  | 1.2            | 1.31 0.97 1.78             | 1.24 0.92 1.69                 |
| Bedtime               |                     |                |                            |                                |
| 21 < 24 49,936        | 584                 | 1.2            | Ref                        | Ref                             |
| 24 < 27 16,045        | 173                 | 1.1            | 0.95 0.80 1.13             | 1.12 0.94 1.33                 |
| Other 1472            | 21                  | 1.4            | 1.29 0.83 1.98             | 1.29 0.84 1.99                 |
| Depth of sleep        |                     |                |                            |                                |
| Very light 4553       | 57                  | 1.3            | 1.01 0.76 1.33             | 0.95 0.72 1.26                 |

<sup>a</sup>RR: Relative Risk; CI: Confidence Interval
factors are thought to be associated with infant development. For women who participated in the JECS study multiple times, data from the second and subsequent participations were excluded (n = 5647). In addition, we excluded cases for which information required for analysis was not available: miscarriage or stillbirth (n = 3676), missing information on maternal age at delivery (n = 7), lack of information about covariates (n = 450), incomplete information on maternal sleep at both M-T1 and M-T2 (n = 3376), missing responses to all questions about children's sleep habits and developmental progress at C-1y (n = 7393).

The remaining 73,827 participants were included in the analysis (Fig. 1). To determine the risk of potential bias due to missing data, we compared the background characteristics between the population analyzed and the population excluded from analysis due to a lack of information about covariates and non-response to any questions about maternal sleep or children's sleep and development (Supplemental Table 3). The group excluded from the analysis had more participants who were less than 25 years old and had smoking habits, lower educational background, and lower household income.

Maternal sleep. The categorization of maternal sleep was done as in our previous research12.

In the M-T1 questionnaire, participants were asked about their awakening time and bedtime before pregnancy. We calculated the sleep duration of participants and divided the participants into six groups according to sleep time: < 6 h, 6–7 h, 7–8 h (reference), 8–9 h, 9–10 h, and > 10 h. Participants were also divided by bedtime:

### Table 5. Association between sleep during pregnancy and infant development, Japan Environment and Children’s Study (2011–2014).

| CI | confidence interval, RR risk ratio. Bold fonts showed the items of the Ages and Stages Questionnaire. a Adjusted for maternal age at delivery, smoking habits, alcohol consumption, pre-pregnancy body mass index, gestational age at birth, parity, infertility treatment, and infant sex. |
|---|---|
| No. of participants | No. of outcome | Maternal age adjusted model | Multivariable modela |
| % | RR | 95% CI | RR | 95% CI |
| Light | 28,224 | 318 | 1.1 | 0.91 | 0.78 | 1.06 | 0.89 | 0.76 | 1.03 |
| Normal | 26,991 | 331 | 1.2 | Ref | Ref |
| Deep | 6451 | 59 | 0.9 | 0.75 | 0.57 | 0.99 | 0.79 | 0.60 | 1.04 |
| Very deep | 1234 | 13 | 1.1 | 0.88 | 0.51 | 1.53 | 0.92 | 0.53 | 1.60 |
| Feeling when waking up in the morning |
| Very bad | 991 | 17 | 1.7 | 1.59 | 0.99 | 2.57 | 1.58 | 0.98 | 2.55 |
| Bad | 13,608 | 179 | 1.3 | 1.17 | 0.98 | 1.38 | 1.16 | 0.98 | 1.38 |
| Normal | 42,104 | 482 | 1.1 | Ref | Ref |
| Good | 9514 | 82 | 0.9 | 0.75 | 0.59 | 0.94 | 0.76 | 0.60 | 0.96 |
| Very good | 1236 | 18 | 1.5 | 1.26 | 0.79 | 2.01 | 1.32 | 0.82 | 2.10 |
| Total (abnormal score for any 1 of the 5 domain) |
| Sleep duration |
| < 6 h | 3187 | 460 | 14.4 | 1.04 | 0.95 | 1.14 | 1.04 | 0.95 | 1.13 |
| 6 < 7 | 10,132 | 1443 | 14.2 | 1.02 | 0.96 | 1.08 | 1.01 | 0.95 | 1.07 |
| 7 < 8 | 21,191 | 2957 | 14.0 | Ref | Ref |
| 8 < 9 | 19,283 | 2547 | 13.2 | 0.95 | 0.90 | 1.00 | 0.97 | 0.92 | 1.02 |
| 9 < 10 | 9531 | 1217 | 12.8 | 0.93 | 0.88 | 0.99 | 0.96 | 0.90 | 1.02 |
| 10< | 4293 | 517 | 12.0 | 0.95 | 0.87 | 1.03 | 0.98 | 0.89 | 1.07 |
| Bedtime |
| 21 < 24 | 50,054 | 6822 | 13.6 | Ref | Ref |
| 24 < 27 | 16,086 | 2118 | 13.2 | 1.00 | 0.95 | 1.04 | 0.97 | 0.93 | 1.02 |
| Other | 1477 | 201 | 13.6 | 1.05 | 0.92 | 1.20 | 1.07 | 0.94 | 1.22 |
| Depth of sleep |
| Very light | 4564 | 601 | 13.2 | 0.93 | 0.86 | 1.01 | 0.94 | 0.87 | 1.02 |
| Light | 28,297 | 3794 | 13.4 | 0.95 | 0.91 | 0.99 | 0.96 | 0.92 | 1.00 |
| Normal | 27,054 | 3762 | 13.9 | Ref | Ref |
| Deep | 6468 | 845 | 13.1 | 0.95 | 0.89 | 1.02 | 0.95 | 0.88 | 1.02 |
| Very deep | 1234 | 139 | 11.3 | 0.83 | 0.70 | 0.97 | 0.83 | 0.71 | 0.98 |
| Feeling when waking up in the morning |
| Very bad | 991 | 133 | 13.4 | 1.04 | 0.89 | 1.22 | 1.05 | 0.89 | 1.23 |
| Bad | 13,641 | 1947 | 14.3 | 1.06 | 1.01 | 1.11 | 1.06 | 1.01 | 1.11 |
| Normal | 42,211 | 5779 | 13.7 | Ref | Ref |
| Good | 9535 | 1143 | 12.0 | 0.87 | 0.82 | 0.92 | 0.86 | 0.81 | 0.91 |
| Very good | 1239 | 139 | 11.2 | 0.81 | 0.69 | 0.95 | 0.81 | 0.69 | 0.95 |
9.00 p.m. to midnight (reference), midnight to 3.00 a.m., and others (sleep before 9.00 p.m. or after 3.00 a.m.). The bedtime for more than 95% of the analyzed subjects was between 21:00 and 27:00. Since the mode of bedtime was between 22:00 and 24:00, we further divided the participants by bedtime 24:00.

In the M-T2 questionnaire, participants were asked about their usual awakening time and bedtime in the last month. The participants were divided into groups as described above for M-T1. Furthermore, the M-T2 questionnaire included two additional questions regarding sleep quality. One was “How would you rate your average depth of sleep during the past month?” The other one was “How would you rate your overall feeling when waking up in the morning, during the past month?” The answers to both questions were scored on a 1–5 scale, representing very light/bad, relatively light/bad, normal (reference), relatively deep/good, and very deep/good, respectively. Both of these questionnaires (M-T1 and M-T2) have not been previously validated.

Outcome 1: offspring’s sleeping problems. One year after delivery, information on infant sleep habits and crying at night was collected via a parent-reported questionnaire (C-1y). The participants answered their infant sleep time in the last 24 h in 30-min increments. They were also asked whether their children cried at night over the last month, and if so, the frequency (“rarely”, “1–3 times in a month”, “1–2 times in a week”, “3–4 times in a week”, “5 times in a week or more”). The questionnaires used for this outcome have not been previously validated. In this analysis, we focused on five points. First, from the responses regarding the infant’s sleep the day before, we determined the number of nocturnal awakenings. A previous study reported that the upper limit of the number of awakenings during the night is 2.5 for 1-year-old infants; as such, we defined ≥ 3 awakenings as too many. Second, we analyzed whether the infants awoke more than once and whether they stayed awake for more than 1 h during the night. Third, we analyzed the duration of nocturnal sleep (from 20:00 to 07:59). We regarded less than 8 h of sleep as unusual. Fourth, we collected information regarding the infants’ bedtime. Based on previous studies, we defined bedtime after 22:00 as too late. Fifth, we analyzed nocturnal crying frequency during the past month. If the mother answered that her infant awoke and cried during the night, and that the frequency of crying at night was more than five times per week, we defined the case as “crying at night”.

Offspring’s development. We used the J-ASQ-3 to evaluate offspring’s development. The C-1y questionnaire included a J-ASQ-3 assessment. J-ASQ-3 captures any developmental delay in five domains: communication, gross motor skills, fine motor skills, problem solving, and personal–social characteristics. The answer to each question is one of the following: “yes”, “sometimes,” or “not yet.” Scores are 10, 5, and 0 points, respectively. Each J-ASQ-3 domain was composed of six questions, and the total score ranged from 0 to 60. Higher scores were defined as more developed, and the cutoff points for every domain in the Japanese version were determined by a previous study. We defined outcomes by whether the score was less than the determined cut-off point of each J-ASQ-3 domain and whether the score was less than the cutoff point of any one of the five J-ASQ-3 domains.

Covariates. Information about maternal age at delivery, smoking habits, alcohol consumption, pre-pregnancy body mass index (BMI), parity, gestational age at birth, infertility treatment, and infant sex, was collected via self-administered questionnaires and/or medical records. These selected covariates were reported as risk factors for developmental disorders.

Statistical analyses. We used a log-binominal regression model to explore the association of maternal sleep with each outcome and to estimate the RRs of each outcome and 95% CIs. We initially adjusted for maternal age at delivery and then further adjusted for smoking habits (never smoked, ex-smokers who quit before pregnancy, smokers during early pregnancy), alcohol consumption (never drinkers, ex-drinkers who quit before pregnancy, smokers during early pregnancy), alcohol consumption (never drinkers, ex-drinkers who quit before pregnancy).
examined the association between maternal sleep during pregnancy and infant’s sleep. We first limited our analysis to the subgroup with 7–9 h of sleep during pregnancy and investigated the association between maternal sleep before pregnancy and infant’s sleep outcome. In the first sub-analysis, we limited it to the participant groups with adequate sleep duration of ≥ 1 h, infertility treatment (no ovulation stimulation/artificial insemination by sperm from husband, assisted reproductive technology), gestational age at birth (37–38, 39–41 weeks), and infant sex (boys, girls). In this study, we did not actively complete any missing data, and all analysis was limited to data from those participants who provided complete information for exposures, outcomes, and covariates. In addition, we performed a sub-analysis twice to evaluate which maternal sleep, the one before or one during pregnancy, impacts the infant’s sleep outcome. In the first sub-analysis, we limited it to the participant groups with adequate sleep duration of 7–9 h during pregnancy and investigated the association between maternal sleep before pregnancy and infant’s sleep. We limited the second analysis to the participant groups with sleep duration of 7–9 h before pregnancy and examined the association between maternal sleep during pregnancy and infant’s sleep.

These statistical analyses were almost the same as those used in our previous study. In this study, we used a fixed dataset “jecs-an-20180131,” which was released in March 2018. Stata version 15 (StataCorp LP, College Station, TX, USA) was used for all analyses.

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