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The impact of reducing the frequency of night feeding on infant BMI

Kelly J. O'Shea[1], **Marie C. Ferguson**[1], **Layla Esposito**[2], **Lawrence D. Hammer**[3], **Cameron Avelis**[1], **Daniel Hertenstein**[1], **Mario Solano Gonzales**[1], **Sarah M. Bartsch**[1], **Patrick T. Wedlock**[1], **Sheryl S. Siegmund**[1], **Bruce Y. Lee**[1]

1.Public Health Informatics, Computational, and Operations Research (PHICOR), CUNY Graduate School of Public Health and Health Policy, New York City, NY

2.Child Development and Behavior, Eunice Kennedy Shriver National Institute of Child Health and Human Development, National Institutes of Health, Bethesda, MD

3.Department of Pediatrics, Stanford University, Stanford, CA

Abstract

Introduction: Teaching caregivers to respond to normal infant night awakenings in ways other than feeding is a common obesity prevention effort. Models can simulate caregiver feeding behavior while controlling for variables that are difficult to manipulate or measure in real life.

Methods: We developed a virtual infant model representing an infant with an embedded metabolism and his/her daily sleep, awakenings and feeds from their caregiver each day, as the infant aged from 6–12 months (recommended age to introduce solids). We then simulated different night feeding interventions and their impact on infant's body mass index (BMI).

Results: Reducing the likelihood of feeding during normal night wakings from 79% to 50% to 10% lowered infant BMI from the 84th, to the 75th to the 62nd percentile by 12 months, respectively, among caregivers who didn't adaptively feed (e.g., adjust portion sizes of solid foods with infant growth). Among caregivers who adaptively feed, all scenarios resulted in relatively stable BMI percentiles, and progressively reducing feeding probability by 10% each month showed the least fluctuations.

Address correspondence to: Bruce Y. Lee, MD, MBA, Professor of Health Policy and Management; Executive Director, PHICOR, CUNY Graduate School of Public Health and Health Policy New York, 55 W 125th Street New York City, NY 10027, bruceleemdmba@gmail.com, Phone: (646) 364-9523, Fax: (646) 364-9600.

Author Contributions:
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Conclusions: Reducing night feeding has the potential to impact infant BMI, (e.g., 10% lower probability can reduce BMI by 20 percentile points) especially among caregivers who don't adaptively feed.

Introduction

Caregivers often rely on feeding in order to soothe infants, beginning soon after birth. Since night awakenings normally occur frequently in infants(1–4), added night-time feedings for infants at least 6 months old may be one of many factors contributing to childhood obesity.(5, 6) As a result, reducing this behavior by teaching caregivers to respond to normal night awakenings in ways other than feeding is a common goal of childhood obesity prevention efforts later in infancy.(7–9) Caregivers and physicians need to understand the impact of such interventions. Many, though not all,(10, 11) interventions that aim to teach caregivers to replace feeding with other soothing behaviors upon infant night waking observe an effect on weight later in childhood.(10–13) Methodological challenges exist within this body of work, with studies often limited by their reliance upon parental report and many potentially confounding variables,(14) including the overall level of responsiveness to infant cues that caregivers show in feeding infants. The question remains, then, to what extent night feeding interventions can be expected to impact infant body weight, given the uncertainty and variability in effectiveness and compliance rates in reality.

Computational modeling can help overcome these limitations by simulating changes to caregiver feeding behavior in the safety of a computer while controlling for variables that are difficult to manipulate or measure in real life. For example, our previous work has explored how caregivers adjusting the portion sizes they feed their infants within feeding guidelines can impact infant weight.(15, 16) Therefore, we developed a computational simulation model representing infant metabolism, hunger, and sleep behavior, and caregiver feeding behavior, to simulate various levels of effectiveness and compliance with an intervention aimed at reducing night feeding in infants 6 months of age and older to determine the impact on infant body mass index (BMI) at 12 months of age.

Methods

Virtual Infant Model

We developed a virtual infant agent-based model in Python(17) representing a virtual infant and their caregiver beginning at six months. Similar to a real infant, each virtual infant has a variety of characteristics including sex, starting length, starting weight and starting BMI. Each infant also has an embedded metabolic model that includes fat mass, fat free mass, physical activity, the thermic effect of feeding, and basal metabolic rate (BMR), adapted from the Hall and Rahmandad metabolic models,(18, 19) as described in previous publications.(15, 16) This metabolic model translates caloric intake and expenditure to corresponding changes to fat and fat free mass.

The model proceeds in one-day time steps, with the infant waking each day in the morning and moving, napping, and feeding throughout the day before going to sleep at night. The infant's physical activity levels are higher when they are awake compared to when they are asleep due to differences in intensity of metabolic equivalents (METs) during wake time and sleep. As a result, the infant uses more calories while awake and less while asleep. We calibrated these values to match observed daily energy expenditure in infants.(20) When the infant wakes up, they stay awake for a period of time, which is determined daily by the following equation:

$$(\text{Total waketime} - \text{nocturnal wakefulness})/(\text{number of naps} + 1)$$

Total waketime is calculated by subtracting total day sleep and total night sleep, which are pulled from distributions (Table 1) from 24 hours. Nocturnal wakefulness and number of naps are also distributions (Table 1).(21) We add one to the number of naps to account for all periods of daytime wakefulness after each nap as well as before the first nap. While the infant is awake, their caregiver decides every hour (between months 6 – 8) or every 1.5 hours (months 9–12) whether to feed the infant breast milk, representing a gradual transition to more frequent and larger solid food portions.(22, 23) Since the composition of breast milk and resulting metabolic responses to breast milk are more consistent, we assumed that all infants consume breast milk. There is much greater variability in the composition of formula and how the body may respond. The infant’s hunger increases linearly over time, with the rate of increase in hunger varying based on age and peaking between 2 and 4 hours.(24, 25) As the infant’s hunger increases, the probability a caregiver decides to feed their infant increases concordantly. Once a caregiver feeds the infant, the infant’s hunger drops to baseline and begins increasing again. At the end of the wake period, the infant falls asleep for a nap; nap duration is based on the average time an infant stays asleep for their age, based on the equation: (Total day sleep)/(Number of naps), where both values are pulled from distributions, as shown Table 1.(21) After the sleep period has concluded, the wake cycle begins again, with the caregiver deciding whether to feed the infant immediately upon waking.

After 6:00 pm each day, the next time the infant falls asleep marks the beginning of night sleep, to approximate the average bedtime for infants under 1 year of age.(26) At night, the infant wakes a certain number of times based on age and is awake for a certain period of time at night (see Table 1). The amount of time an infant is awake during each night waking is determined by the calculation: (total nocturnal wakefulness)/(total number of night wakings). Upon night waking, the caregiver has a 79% probability of feeding the infant when there is no intervention.(27, 28)

Each daytime and nighttime feed is a certain amount (portion size in kilocalories) consistent with empirical averages for breastfed infants according to age.(20, 29, 30) Daytime feedings consisted of breast milk as well as solid food meals. We calculated the mean of the portion size range of solid foods to correspond to the remaining energy requirements of the age of the infant(20) after subtracting the typical portion size of breast milk according to age.(29) Nighttime feedings consisted of breast milk only.

To represent caregivers with adaptive feeding behaviors, virtual caregivers could assess if and how to respond to their infant’s growth on a weekly basis. As described in our previous studies,(15, 16) caregivers start off feeding an amount of solid food from the full range (Table 1), and if the infant's BMI increases and passes a major BMI percentile (5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th} and 95^{th}), then the caregiver will reduce the amount they feed their infant, using an amount from the lower half of this distribution.

If an infant's BMI continues to increase and crosses another major BMI percentile and they are already consuming the lower end of the range, then they will continue to consume portions at the lower end. If their BMI starts to decrease and crosses a major BMI percentile by the next week, the caregiver will adjust and feed from the full range. If after another week their BMI continues to decrease and crosses another major BMI percentile, the caregiver will adjust to the upper half. We allowed for only one adjustment per week, such that the portion size would not jump from the lower half to the upper half in one week.

Validation of Simulation Model

Data used to validate the model were separate from all model input data (Table 1). As shown in our previous studies, we compared infant weights when virtual infants (15^{th} to 85^{th} BMI percentile) were fed the age and BMI percentile-specific total energy requirements from Butte(20), to the infant weights presented in the World Health Organization (WHO) growth curves. The outputs were not statistically different from the data.[21,30] For example, a 50th BMI percentile virtual female weighs 6.058 kg at three months of age (compared to 5.84 kg on the WHO growth curve), 7.376 kg at six months of age (compared to 7.297 kg on the WHO growth curve), and 8.244 kg at nine months of age (compared to 8.225 kg on the WHO growth curve).

After introducing infant sleep cycles, we compared total sleep duration to the reference curves established by Iglowstein, et al.(26) Model-generated output showed that the total sleep duration of a six-month-old virtual infant was, on average, 13.4 hours (standard deviation [SD]: 0.8) and nocturnal wakefulness was 0.8 hours (SD: 0.2). This is comparable to the total sleep duration reported by Iglowstein, et al, (mean of 14.2 hours [SD: 1.9]). For a virtual 12 month old, model-generated total sleep duration was, on average, 12.8 hours (SD: 0.6) with an average of 0.5 hours (SD: 0.1) of nocturnal wakefulness compared to the total sleep reported mean of 13.9 (SD: 1.2) hours. The model values are not statistically different from Iglowstein. As expected, the total sleep generated by the model is higher than total sleep reported by Iglowstein, et al. which did not subtract nocturnal wakeful periods.

Modeled Interventions

Experiments consisted of 1,000 runs. We first simulated individual infants' growth over the course of six months (6 – 12 months) without any night feeding intervention, both with and without adaptive caregiver feeding behaviors. Our simulations began at the age of 6 months, before which solids are generally not recommended for breastfed infants and night feeding is encouraged;(27) some literature suggests that behavioral night feeding interventions may not be developmentally appropriate earlier in life.(31) To simulate various success rates for an educational intervention targeting the reduction of night feeding by infants' caregivers, we tested various reductions in the probability of night feeding. We reduced the probability of feeding an infant during each night waking, ranging the probability from 70% to 10%

beginning in month 6 (down from 79% when there was no intervention). We then explored the possibility of progressively reducing the probability of night feeding each month so that it was 69% in the sixth month, then decreasing by 10 percentage points each month until reaching 29% in the eleventh month. We conducted our full range of experiments first without adaptive feeding behavior in caregivers and then repeated experiments while including this behavior (e.g., when caregivers can adjust the amount of solid food they feed their infant depending on their growth). Sensitivity analysis increased and decreased the total duration night sleep by a relative 10%.

Results

No Intervention

When caregivers did not adjust portions in response to changes in body weight (representing less adaptive overall feeding practices), average BMI percentile continues to rise each week, beginning in week 27, ending at the highest point of 84th BMI percentile (95% confidence interval [CI]: 83–85), as is shown in Figure 1. When caregivers adjust portions in response to changes in body weight (representing more adaptive feeding practices), the average BMI percentile remains more stable, peaking at the 61st BMI percentile (95% CI: 59–62) in week 32 and then beginning to level off to end at the 55th percentile (95% CI: 53–58) (Figure 2).

Impact of Night Feeding Interventions Without Adaptively Feeding based on Infant Growth

When caregivers do not adjust portion sizes, reducing their probability of feeding their infants upon night waking to 70% result in lower average BMI percentiles over time compared to the baseline probability, though the line follows the same upward trajectories, ending at the 82nd (95% CI: 81–83) percentile as seen in Figure 1. Reducing the probability of feeding upon night waking to 50% results in a similar trend, ending at the 75th (95% CI: 74–76) percentile. Reducing the probability to 10% produced variations in average BMI percentile that remained within the 62nd percentile (95% CI: 60–62) at the highest and the 56th percentile (95% CI: 56–57) at the lowest.

Finally, progressively reducing the probability of feeding upon night waking so that it was 29% in the eleventh month resulted in a differently shaped growth curve, with BMI percentile stabilizing after 33 weeks (8.25 months of age), varying from the 70th percentile (95% CI: 70–71) at the lowest to the 72th percentile at the highest (95% CI: 70–73).

Impact of Night Feeding Interventions With Adaptive Feeding based on Infant Growth

Reducing the probability of feeding upon night waking to 70% or 50% results in slightly lower average BMI percentiles compared to baseline, with reductions of 2.1 percentile points and 5 percentile points at most at week 37, respectively. When reducing probability of feeding upon night waking to 10%, infant BMI was 10 percentile points below the baseline at week 37 (the time point of greatest divergence) averaging at the 48th BMI percentile (95% CI: 47–49) and averaging at the 53rd BMI percentile (95% CI: 51–54) at the end of the first year. As shown in Figure 2, when caregivers respond to 10%, 50% and 70% of night feedings, the average BMI percentiles of infants ultimately converge within the confidence interval of the baseline scenario at 52 weeks

Reducing the probability of feeding upon night waking by 10 percentage points each month until reaching 29% in the eleventh month, resulted in the lowest ending BMI percentile at 51 (95% CI: 49–53) compared to other experimental scenarios.

Varying Total Sleep and Number of Night Wakings

As shown in Figure 3, when caregivers did not adaptively feed and infants' total night sleep time decreased by a relative 10%, we found that there were more opportunities to feed, with an average of 7.17 feedings per day (95% CI: 7.15–7.18) for those with 10% less sleep compared with 6.44 feedings per day (95% CI: 6.43–6.45) at baseline. Thus, when total sleep decreased consumption increased, and the infants' average BMI neared the obese weight category at the end of one year (94th BMI percentile). When caregivers did not adaptively feed infants and total sleep increased by a relative 10%, we found that BMI followed a similar trajectory compared to the baseline (not adjusting total sleep) and was at the 71st BMI percentile at the end of one year (Figure 3). Simulations with a caregiver who did adaptively feed their infant initially showed similar trends to the non-adaptive feeding caregiver, with increased sleep resulting in lower BMI and decreased sleep resulting in higher BMI. However, after 40 weeks, caregivers adjusting portion sizes due to infant growth compensated for the changes in growth due to sleep and ultimately resulted in the infant with less sleep having, on average, a lower BMI compared to infants at both the baseline and with increased total sleep by 10% (Figure 4). This demonstrates that our model is more sensitive to caregivers adjusting portion sizes than changes to total sleep (+/− 10%).

Discussion

This study shows the impact of night feeding interventions on infant BMI when reducing a caregiver's likelihood of feeding their infant during wake time at night. We found that while there is value in an intervention that reduces the probability of feeding upon night waking to 70%, interventions that reduce the probability to 10% can reduce infant BMI by over 20 percentile points (e.g., 84th percentile to 62nd percentile), and further, infants maintained their BMI percentile between 6 and 12 months, among caregivers who did not adaptively feed them based on their growth. Among caregivers who adaptively fed their infants, progressively reducing the probability of feeding by 10% each month showed the most stability in BMI percentile between months 6 and 12. Thus, our study showed that as infants over the age of six months were fed less at night, they attained a lower BMI percentile at twelve months, which supports clinical guidance to night-wean infants as appropriate based on their health statuses and growth trajectories. These findings may be of interest to researchers and clinicians in the fields of child obesity, pediatric and behavioral sleep medicine, child psychiatry, developmental-behavioral pediatrics, and primary care. Although the paper was not intended to test specific hypotheses involving sleep disturbances and parental feeding decisions, it may serve as an impetus toward greater study of the interrelationship between feeding and sleep issues in children.

Results also show that night feeding interventions have a more substantial impact for caregivers who do not adaptively feed their infant based on their growth compared to caregivers who do adaptively feed their infants. This may be because caregivers who do not adaptively feed their infants have more "room for improvement" and so the impact of the intervention is more prominent compared to interventions with caregivers who are already adjusting feeds, even if those adjustments are not directly tied to sleeping and waking.

Our model did not make any assumptions about what caregivers did when infants woke in the night rather than feeding, and interventions vary in what they train caregivers to do. This could entail other ways to soothe infants, often in conjunction with a larger responsive parenting curriculum(12, 32); some, conversely, encourage caregivers not to respond to night wakings at all, which is thought to encourage longer sleep durations and fewer night wakings(33, 34) but is not without controversy.(35–37) However, reducing night feeding may be one of the simpler parenting interventions to follow, since caregivers do not have to learn to recognize cues to reduce the frequency they feed their infants at night.

It is known that a variety of factors contribute to excessive weight gain, so in considering the impact of changing any single behavior (e.g., reducing night feeding), a big picture perspective is important. This simulation shows that, especially for caregivers who are not adaptively feeding, reducing night feeding in response to wakening is one strategy that could help promote healthy growth, but alone might not move the needle. For caregivers who are already engaged in adaptive feeding, infants experience diminished changes to their average BMI percentile. Thus, incorporating this strategy as one of several tools in a multi-component intervention for obesity prevention for very young children is likely the most promising opportunity for the biggest impact. One key contribution of the work is that it can inform how including this intervention component has the potential to impact BMI, and which caregivers it might be most impactful for.

Limitations

All models, by definition, are simplifications of reality and do not include every possible variable. Sleep in infants is complex but has been simplified for the purpose of the model. For example, we did not include the potential effects of sleep on hunger and satiety hormones, which have been observed in other age groups but not quantified in infants.(38–40) The entrainment of homeostatic, circadian, and ultradian rhythms, as well as the connections from sleep patterns to the hormonal regulation of stress and hunger, have all been less studied in infants than in adults. Macronutrient composition of food intake is not represented in the infant metabolic model, which may affect growth patterns. Physical activity is also challenging to study in infants and is represented simplistically.

Conclusion

This study shows that night feeding interventions have a more substantial impact for caregivers who do not adaptively feed their infant based on their growth compared to caregivers who do adaptively feed their infants. While there is value in an intervention that reduces the probability of feeding upon night waking to 70%, interventions that reduce the probability to 10% can reduce BMI by over 20 percentile points (e.g., 84th percentile to 62nd percentile) among infants with caregivers who do not adaptively feed them based on their growth.

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Impact Statement:

- Teaching caregivers to respond to infant night waking with other soothing behaviors besides feeding has the potential to reduce infant BMI.
- When reducing the likelihood of feeding during night wakings from 79% to 50% to 10% infants dropped from the 84th BMI percentile to the 75th to the 62nd by 12 months, respectively, among caregivers who don't adaptively feed.
- Night-feeding interventions have a greater impact when caregivers don't adaptively feed their infant based on their growth compared to caregivers who do adaptively feed.
- Night-feeding interventions should be one of several tools in a multi-component intervention for childhood obesity prevention.

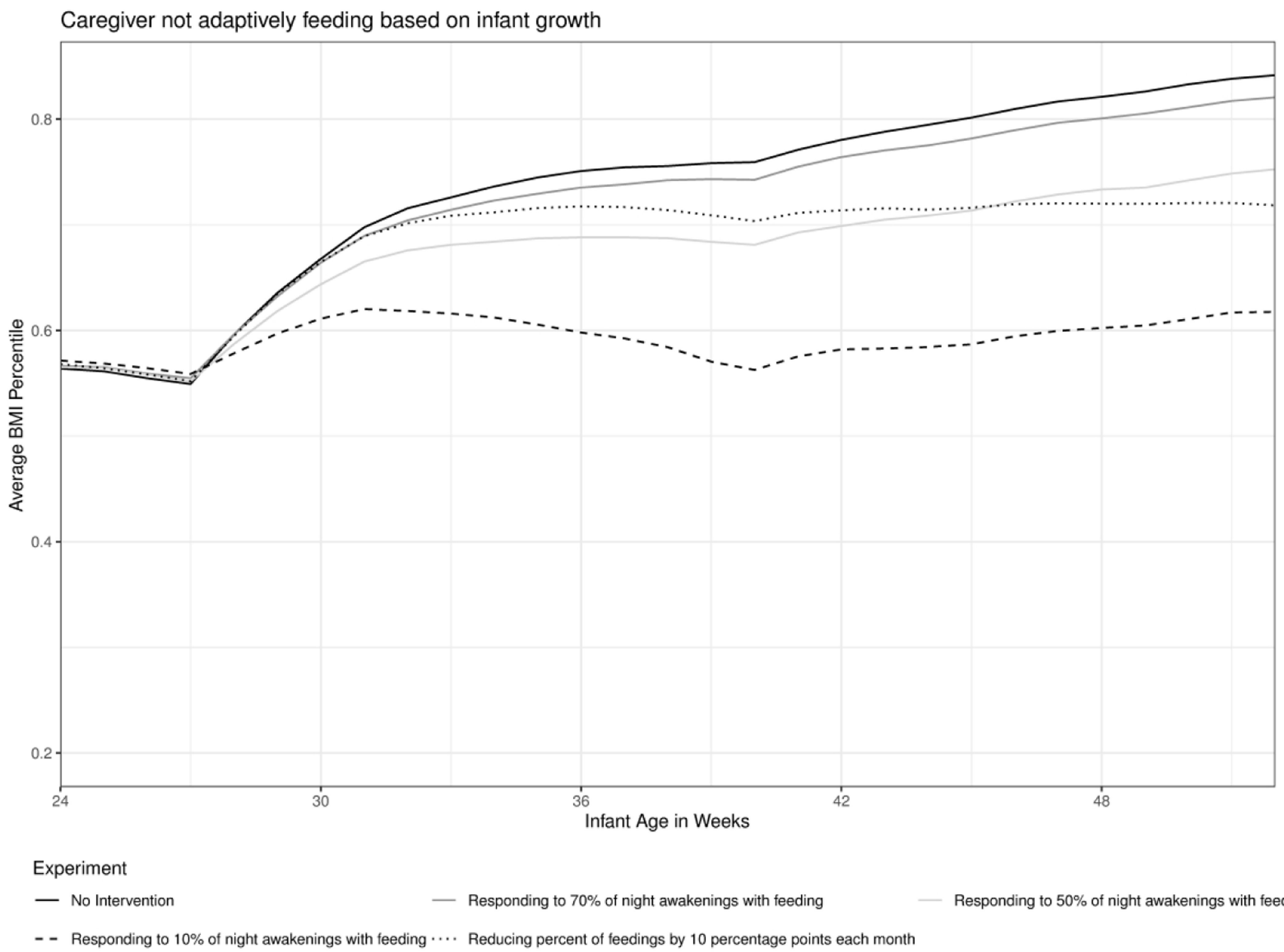

Figure 1.

Assessing the impact of an intervention that reduces the number of night feeds on infant BMI for 6 Months, without adaptive feeding.

Experiments simulated a reduction in the number of times virtual caregivers respond to infant night awakenings with feeding. In these scenarios, virtual caregivers did not adjust to the infants' weight trajectory by feeding in the lower or upper quartile of feeding amounts in response to significant weight gain or loss, respectively.

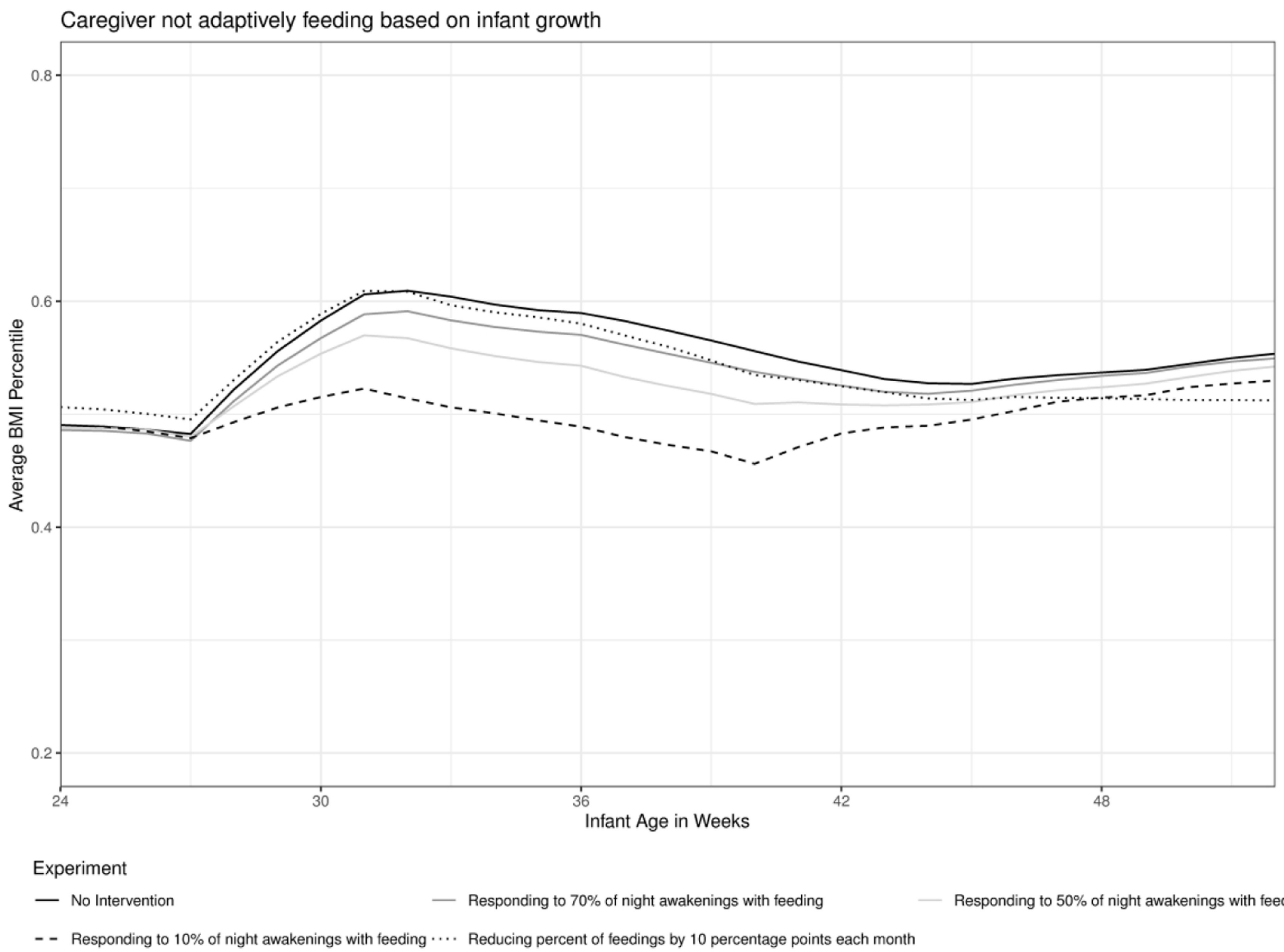

Figure 2.

Assessing the impact of an intervention that reduces the number of night feeds on infant BMI for 6 Months, with adaptive feeding.

Experiments simulated a reduction in the number of times virtual caregivers respond to infant night awakenings with feeding. In these scenarios, virtual caregivers adjusted to the infants' weight trajectory by feeding in the lower or upper quartile of feeding amounts in response to significant weight gain or loss, respectively.

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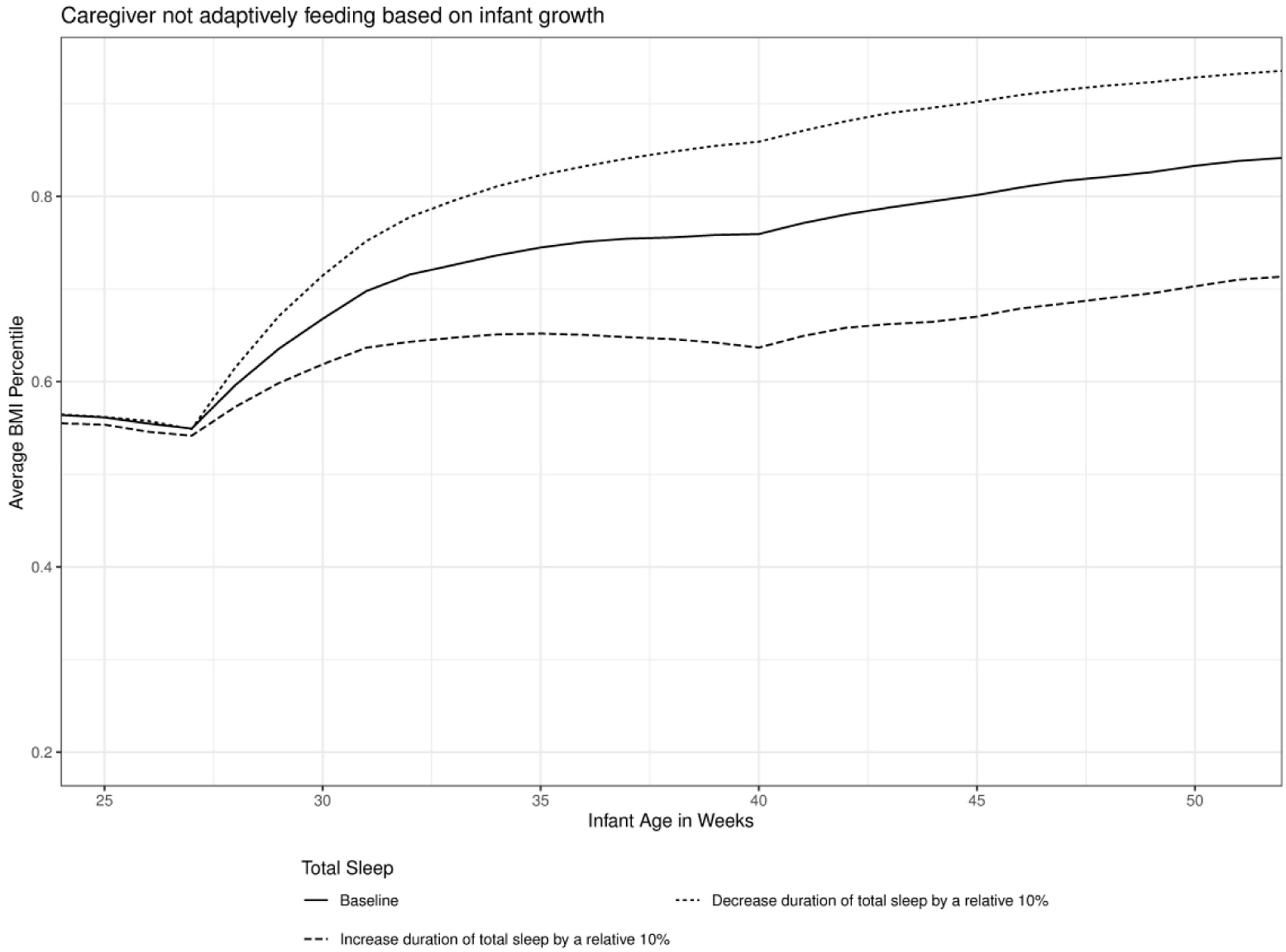

Figure 3.

Assessing the impact of varying duration of total sleep, without adaptive feeding. Experiments simulated a reduction in the number of times virtual caregivers respond to infant night awakenings with feeding. In these scenarios, virtual caregivers adjusted to the infants' weight trajectory by feeding in the lower or upper quartile of feeding amounts in response to significant weight gain or loss, respectively.

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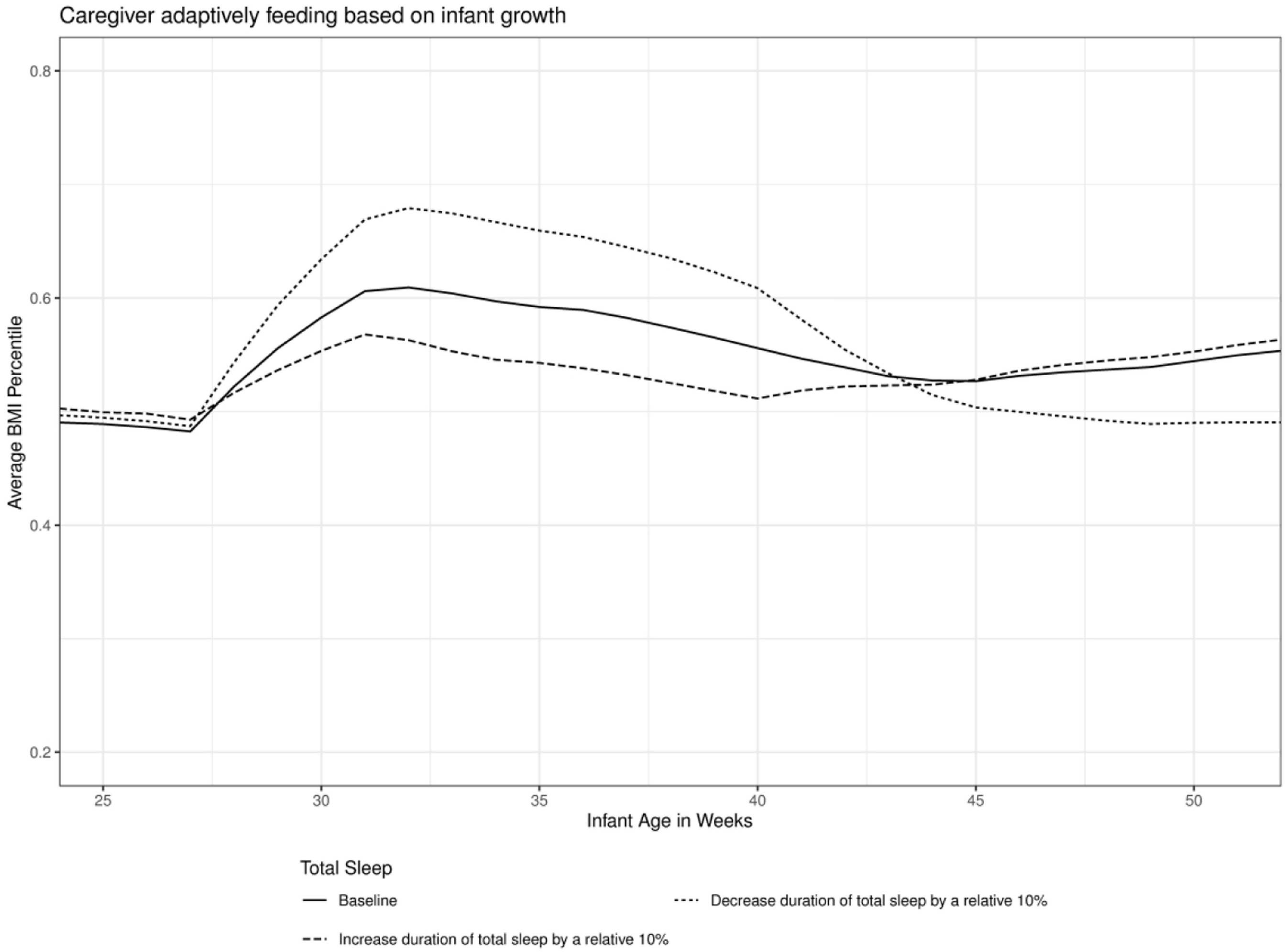

Figure 4.

Assessing the impact of varying duration of total sleep, with adaptive feeding. Sensitivity analyses simulated an increase and a reduction in total night sleep by a relative 10%. In these scenarios, virtual caregivers adjusted to the infants' weight trajectory by feeding in the lower or upper quartile of feeding amounts in response to significant weight gain or loss, respectively.

Table 1.

Table of Inputs

Infant age in months	**6**	**7**	**8**	**9**	**10**	**11**	**Ref**
Day sleep							
Number of naps (mean, SD)	2.42, 0.75			2.02, 0.52			22
Total day sleep (mean, SD)	3.01, 1.2			2.82, 1.04			22
Time between naps	(Total waketime – Nocturnal wakefulness)/(Number of naps + 1)						
Nap duration	(Total day sleep)/(Number of naps)						
Night sleep							
Nocturnal wakefulness in hours (mean, SD)	0.36, 0.48			0.31, 0.47			22
Number of awakenings (mean, SD)	1.25, 1.20			1.16, 1.17			22
Total night sleep in hours (mean, SD)	12.9, 1.9			12.8, 1.59			22
Physical Activity							
METs during sleep	0.40			0.38			31
METs during wake time	1.05			1.02			31
Consumption							
Solid food portion size in kilocalories (mean, SD)	64.84, 32.12)	70.91, 32.12)	73.94, 32.12)	89.53, 38.84	96.51, 38.84	98.84, 38.84	31
Solid food frequency	3.3	3.3	3.3	4.3	4.3	4.3	29
Breastmilk portion size in kilocalories (mean, SD)	59.27, 15.15	55.86, 15.15	56.51, 15.15	45.18, 36.70	45.73, 36.70	48.10, 36.70	30